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MICROSTRUCTURE SENSITIVE MODELING OF TEMPERATURE DEPENDENT YIELD BEHAVIOR OF FULLY LAMELLER TiAl

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1 INTRODUCTION

Fully lamellar titanium aluminide (TiAl) alloys are increasingly used as structural materials in high temperature lightweight applications like e.g. turbine blades in aircraft engines or turbocharger wheels and engine valves in automotive industry. Their beneficial combination of good thermomechanical properties with a comparatively low density attracted considerable research attention over the last decades. Due to these research activities, the developed TiAl alloys grew more and more powerful and weaknesses like their intrinsic brittleness were understood and reduced. Despite the great improvements in understanding the complex (micro)mechanics of fully lamellar TiAl alloys, there is still no comprehensive constitutive model reported yet, which is able to predict their behavior over the big temperature range these alloys encounter in service. A respective model would proof helpful to max out the benefit from their outstanding properties in machine part design.

2 MICROSTRUCTURE AND MICROMECHANICS

Fully lamellar microstructures consist of grain-shaped lamellar colonies with a domain structure along the lamellae that originates from the strict orientation relation between the lattices of the two constituent phases.

To selectively analyze the complex micromechanics of fully lamellar TiAl alloys, so-called polysynthetically twinned crystals – basically a single set of parallel aligned lamellae – proved essential. Experimental results from literature[1,2,3] illustrate, e.g., the pronounced plastic anisotropy, the influence of the various microstructural boundaries, dependence of yield stress on temperature and phase distribution as well as creep, fatigue and failure mechanisms.

3 CONSTITUTIVE MODELING

Since the macroscopic behavior of fully lamellar TiAl alloys is highly influenced by their complex thermomechanical behavior on meso and micro scale, micromechanical models – especially crystal plasticity based ones – proved to be most effective for the intended modeling purpose.

3.1 State of the art

All crystal plasticity models of TiAl alloys, published so far, are either limited to room temperature and/or isothermal conditions without accounting for the thermomechanics of the alloys. Moreover, the material parameters identified for these models are in most cases only valid near a certain temperature or for a specific set of microstructural parameters (e.g. lamella thickness), necessitating a model recalibration in order to study the influence of a different microstructure or changing operating temperatures.

3.2 Thermomechanically coupled crystal plasticity model

Since the precise thermomechanical description of the material is crucial, our aim is to set up a thermomechanically coupled, microstructure sensitive crystal plasticity model which incorporates all important micromechanical effects over the relevant temperature range.

From the experimental data in[1,2,3], we extract the relevant micromechanical effects and consecutively expand the underlying thermomechanically coupled crystal plasticity finite element formulation by appropriate constitutive equations. In this constitutive modeling procedure, we incorporate the different sources of Hall-Petch strengthening as well as the yield stress temperature anomaly – commonly observed in intermetallics – via the critical resolved shear stresses[4].

From the description of a polysynthetically twinned crystal the model can easily be transferred to a representative volume element of a polycrystalline fully lamellar microstructure enabling the analysis of the behavior of technically relevant alloys.

4 RESULTS

The results obtained from simulations are in good agreement with literature experimental findings, proving the models ability to predict the yield stress of polysynthetically twinned TiAl crystals over a wide range of temperatures and microstructural parameters.

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