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APPLICATION OF MICROMECHANICS TO COMPONENT DESIGN

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Summary. Recently a lot of research has been focused on developing micromechanical analysis of solids, such as steel and cast irons. However, using this knowledge in industrial component design is still limited by the computational resources. In this paper, we introduce a strategy for applying micromechanical models in a computationally feasible way to real life product development.

1 INTRODUCTION

Fatigue is a significant phenomenon in many structure failures. Even though fatigue is easily observed and has real life consequences, the initiation and evolution of fatigue is still quite unknown. Dozens of criteria and diagrams have been developed for macroscale applications, but only a few in mesoscale. Using micromechanics in finite element simulations is still a relatively new trend and a quite uncharted area, which serves as the motivation for this study on the applicability of micromechanical models in the fatigue analysis of machine components.

2 CRYSTAL PLATICITY

The methodology presented is based on a mesoscale model working on the crystal structure level typical for several metals, such as steels. The key feature is to use the slip systems of the crystal structure to generate strain. There are two kinds of crystal plasticity models: single crystal and polycrystal model. The single crystal model main usage area is in the mesoscale models and the polycrystal model in the macroscopic models. Both single crystal material model and polycrystal material model are phenomenological models.

In this context, crystal plasticity models are used to predict the mechanical behavior on the mesoscale. Since the complexity of such models is high, these models are typically smaller in size, and subsequently not directly useful for component level simulations.

3 METHODOLOGY FOR ASSESSING FATIGUE ON THE MACROSCALE BASED ON MESOSCALE RESULTS

To assess fatigue in large machine components, a macroscopic presentation of the component is needed. However, effects such as grain flow in forged components couple the fatigue behavior directly to effects visible on the micro- or mesoscale. For example, grain flow affects the fatigue behavior due to the different orientation of inclusions naturally found in metals.

3.1 Fatigue evaluation

The methodology is based on the notion of modifying a macroscale fatigue prediction methods, such as the Dang Van[1] method to be micromechanically informed, i.e. taking into account the aforementioned grain flow. To this end, we will employ the mesoscale model to predict the effect of grain flow on the parameters of the Dang Van criterion based on the model, not on physical fatigue testing. This procedure allows us to easily assess a multitude of different loading – material orientation combinations and use these as a parameter library for the component level simulation.

3.2 Plasticity-based fatigue indicator

A coupled plasticity – damage material model is used as the damage indicator. In this study, we neglected the coupling between the damage and the mechanical response, since we are working in the high cycle regime where the strains are typically low enough to justify this simplification. We use the evolution of an internal porosity parameter of the material as the damage indicator as proposed by Monchiet et al. in [2]. When the porosity reaches a stable value, no damage is interpreted to occur, should the porosity continue to grow without a limiting value, the material is deemed to fail. By iterating these results, we find the fatigue limit of the material in the given loading – orientation configuration and employ these results to fit a given fatigue model, such as the Dang Van model.

4 CONCLUSIONS

The methodology presented shows some promising results in using microscale models in real-life engineering applications. However, great emphasis should be put on validating and choosing the correct constitutive model, since this ultimately defines how accurate the fatigue prediction is based on the mesoscale model. It is also evident, that with the current computer hardware, micromechanical models start to provide an effective means of amplifying the availability of data on fatigue phenomena based on different micromechanical phenomena, such as grain flow effects and different types of inclusions present in the material.

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