Executive Summary

Single crystal Ni-base superalloys (SX) are used for blades in fossil fuel fired power plants and aero engines. Here they have to withstand high mechanical stresses at temperatures close to their melting point. The blades are manufactured by a Bridgman type of directional solidification, followed by a multiple step heat treatment. During the dendritic solidification, pores can form due to undissolved gas, macroshrinkage by inadequate gating and microshrinkage caused by poor feeding between dendrites. Additional pores can form in the interdendritic regions during the multiple step heat treatment which follows solidification. It is believed, that these pores form on the basis of a Kirkendall effect which accounts for the fast diffusion of Al atoms away from microstructural regions with non-equilibrium γ/γ′ eutectic. During creep, pores can grow and change their shapes. It has been shown, that during creep in the high temperature / low stress regime new pores form, which are smaller than those pores that can be found in the undeformed material.

In the present work, the evolution of porosity in the single crystal Ni-base superalloy ERBO/1 during processing and creep is investigated. Quantitative microstructural analyses were performed on metallographic cross sections. Sampling fields of 4500 x 1000 µm² were investigated by using a combination of scanning electron microscopy with quantitative image analysis. Interrupted creep tests with a miniature tensile creep specimen were performed with load direction parallel to <100> and <110> direction, respectively. Pore parameters (area, perimeter, Feret’s diameter) for individual pores were obtained and two form factors were introduced. The evolution of the compiled statistical distributions of pore parameters and shape factors are discussed. The results are compared to recent findings by Link et al., 2006 and Mälzer et al., 2007.

In the present study it was shown that the quantitative metallographic approach is able to qualitatively reproduce all important details of porosity evolution, which were identified by Link et al. using synchrotron radiation. Pores which the metallographic method detects directly after casting appear in a low density (17 pores/mm²) and show very broad log-normal size distributions. Solidification pore sizes (in terms of pore areas on the metallographic cross section) can vary from 2 to 200 µm². During the multiple step homogenization heat treatment of ERBO/1, new pores form and the pore density increases to 34 pores/mm². Simultaneously, one can detect an increase in average pore sizes. The size distribution of pores shifts to higher values. During high temperature and low stress creep, new small pores form (pore density increases to values ranging from 139 pores/mm² to 193 pores/mm²) and the size distributions evolve from unimodal (as-cast and heat treated material state, prior to creep) to bimodal (early stages of creep).

The present study furthermore represents the missing link between the synchrotron studies of Link et al., 2006 regarding the evolution of porosity and the metallographic investigations of Mälzer et al., 2007, who investigated the role of pores with respect to creep rupture. The advantage of the present
study is that both, the investigation of porosity evolution and the investigation on the role of pores on creep rupture, were performed with one alloy at the same temperature / stress conditions.

It has been shown, that the distribution of pores in the material and the alignment of pores relative to the loading direction are important. Mälzer et al. showed, that creep specimens with pores aligned parallel to the loading direction ([001] specimens) showed higher rupture strains compared to specimens, where pores were aligned perpendicular to the loading direction ([110] specimens). These findings have been confirmed by the present study. The metallographic results, presented in this work, suggest that creep rupture is associated with the formation of microcracks at larger solidification and heat treatment pores, which can grow, interlink and initiate final creep rupture. Creep pores appear, due to their size, to be less important with respect to creep rupture. The alignment of pores along the dendrites and their relative position to the loading direction are the key factors, that can limit creep life.

Finally, the influence of the crystallographic orientation on the evolution of porosity was investigated. It has been shown, that there are no fundamental differences of the size and shape factor distributions, when [001] and [110] oriented specimens are compared, but there are differences in the appearance of crystallographic facets and an orientation dependency of pore growth is suggested.