Development of a Prediction-Model for the Influence of Porosity on the Mechanical Properties of Cast Lightweight Components

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Abstract

Based on geometrical data of porosity obtained by computer tomography, a micromechanical unit cell model is proposed to predict the influence of porosity on mechanical properties of high performance cast alloys. Simulations of uniaxial loaded periodic unit cells are compared to experimental data of tensile tests on porous materials. In this way a relationship between some significant geometrical data of the pores and the macroscopic material is obtained.

Introduction

For the design and quality-evaluation of cast high performance light weight components, the knowledge of the effect of porosity on strength and durability is of high significance. A model on the mesoscopic scale is proposed to investigate the impact of the topological aspects of casting defects on the macroscopic mechanical properties of the material.

Determination of morphological and topological characteristics of pores

Specimens of as-cast material were investigated using computed tomography [1]. The data are used to evaluate some geometrical characteristics of porous specimens like the volume fraction and the arrangement of pores as well as radii of curvature and characteristic lengths of individual pores. The geometries of some representative pores were obtained to serve as geometrical input for the mechanical model by using high resolution measurements (resolution about 3 µm).

Modeling of mechanical properties and experimental validation

The geometry of the pores obtained by computed tomography is embedded into a cuboidic unit cell as shown in Fig. 1. Using periodic boundary conditions [3], the behavior of an infinite porous continuum subjected to different stress or strain states can be investigated. As a result the homogenized macroscopic behavior of the porous material is obtained (cf. Fig. 2). In a second step this model is optimized by simplification and generalization to obtain predictions for the mechanical properties of porous materials. It has arisen that using ellipsoidical approaches is not sufficient to represent the branched morphology of the pores. For this reason a more complex simplification is proposed.

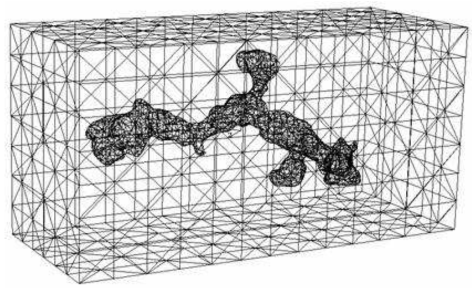

Fig. 1: Cuboidic periodic cell including a single pore, surface meshes of the finite element discretization

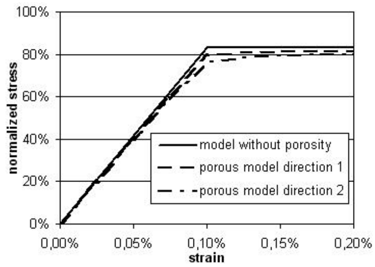

Fig. 2: Detail of the response of a porous periodic cell to uniaxial mechanical load

For the validation of the model experimental investigations are conducted. Using a deformation dilatometer for uniaxial tensile testing, the elastic and elastoplastic properties are obtained of porous and non-porous specimens. The tensile tests are conducted isothermally at room temperature and at 900°C. The volume fraction of the porosity of the as-cast specimens is measured by computer tomography. The mechanisms of damage are investigated on broken specimens by micrographs and SEM-analysis near the fracture surface to be implemented in the model in a further step of improvement. The aim is to identify the parameters being adequate for the description of the mechanical behavior of the porous region with sufficient accuracy from data gained by non-destructive testing. These parameters can then be used to estimate the mechanical behavior of porous materials and finally the strength and durability of porous components.

Summary and Outlook

The proposed model allows estimating the macroscopic behavior of a porous material affected by geometrical properties of its porosity. Enhancements are in progress like the development of a substitute pore-geometry, capturing the important geometrical characteristics. This substitute model will enable the investigation of arrangements of several pores within the unit cell.

[1] Kropas-Hughes, Neel, Materials Evaluation (USA) 58/5, 630–633 (May 2000).

[2] Sánchez, Narciso, Rodríguez-Reinoso, Bernard, Watson, Lee, Dashwood, Advanced Engineering Materials 8/6, 491–495 (June 2006).

[3] Böhm, CISM Cours and 12th IUTAM Summer School ”Mechanics of Microstructured Media”, Udine, Italy, 19–24 (July 2003).