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Onset of fracture in high pressure die casting aluminum alloys

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Abstract

This paper deals with the development of a phenomenological criterion for the prediction of crack initiation in engineering structures made of the pressure die casting alloy Al–10Si–Mg–Mn. A custom-made biaxial testing device is employed to load a newly-designed flat specimen under various combinations of shear and normal loading. In a hybrid experimental–numerical approach, the crack initiation could be studied for stress triaxialities ranging from about 0.0 to 0.6. A phenomenological fracture criterion has been calibrated which predicts the onset of fracture based on the stress triaxiality and the maximum principal strain. The results from post-mortem metallographic analysis suggest that fracture of Si-particles leads to the macroscopic crack formation at stress triaxialities above 0.25, whereas Al-matrix instability failure along with particle–matrix delamination seems to initiate macroscopic cracks at stress triaxialities around 0.0.

Keywords: Aluminum alloy; High pressure die casting; Fracture criteria; Stress triaxiality; Failure mechanism

1. Introduction

Substantial progress has been made during the past decade in the development of pressure die casting alloys and processing technology (e.g. [15,21]). High pressure die casting components made of aluminum- or magnesium alloys offer various advantages in automotive applications. In particular, the cost efficiency of the casting process and the possibility to cast thin-walled components of complex geometries led to the use of this class of materials in modern lightweight vehicles. Examples include crash relevant car body parts like the B-pillar or pressure cast instrument panels, which may be characterized by a high level of function integration. Throughout the virtual car development process, it is of foremost importance to use reliable models to predict the mechanical behavior of individual materials. In the case of pressure castings, this involves the modeling of

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the elasto-plastic material response as well as the prediction of fracture. The later is of particular interest in misuse- and crash simulations where failure of individual components may change the overall performance of the vehicle.

The onset of fracture in uncracked bodies made from aluminum or steel is frequently predicted based on the current void fraction in the material. This approach requires the knowledge of the initial void volume fraction, the void nucleation (e.g. [13]) as well as the modeling of the void growth as the metal is subject to irreversible deformations (e.g. [18,23,8,24]). Moreover, in order to predict the onset of fracture, the critical void volume fraction must be determined either from direct measurements or from calibration of the model parameters (e.g. [12,16,22]). As an alternative to porous plasticity based fracture prediction, phenomenological fracture criteria are frequently used to predict the onset of fracture in metals (e.g. [6,4,9]). Such criteria predict the crack initiation based on the macroscopic stress and strain fields. Since the hydrostatic stress strongly affects the rate of void growth and nucleation in most ductile metals, phenomenological fracture criteria typically predict the domain of admissible plastic strain states as a function of the stress triaxiality.

This work deals with the onset of fracture in pressure die castings made of the Al–10Si–Mg–Mn alloy. In view of large-scale computations in automotive engineering, we limit our attention to the development of a phenomenological fracture criterion which can be used in conjunction with computationally-efficient J_2-plasticity algorithms. The starting point is a series of biaxial experiments. A custom-made testing device along with a newly-developed flat specimen is employed to investigate the crack initiation at stress triaxialities ranging from 0.0 to 0.6. Subsequently, numerical simulations are carried out to determine the phenomenological fracture criterion in the form of a limiting envelope in the maximum principal strain versus stress triaxiality plane. Furthermore, post-mortem metallographic analysis is performed to gain some insight into the mechanism of crack initiation at both low and high stress triaxialities.

2. Material

We consider a solidified high pressure die casting alloy composed of aluminum (Al), silicon (Si), magnesium (Mg), and manganese (Mn). The exact weight percentages of the chemical constituents of the Al–10Si–Mg–Mn alloy are given in Table 1. Thin-walled components have been manufactured from this alloy using a vacuum-assisted pressure casting process. All castings have been subject to T7 heat treatment which enhances the ductility of the Al–10Si–Mg–Mn alloy. The specimens for mechanical testing have been extracted from 2.8 to 3.0 mm thick sections of the pressure cast components (two specimens per casting). Moreover, the location of specimen extraction has been chosen close to the gate system. Thus, the porosity within the specimens was fairly low. Using computer tomography (Scanco Medical μCT40), we determined an average initial porosity of about 0.25 vol.%.

2.1. Microstructure

The microstructure of the heat treated Al–10Si–Mg–Mn alloy is composed of dendritic aluminum cells which are surrounded by eutectic silicon particles. The light and dark regions in Fig. 1a correspond to the aluminum matrix and silicon particles, respectively. Several micrographs have been evaluated using digital image analysis. The shape aspect ratio of the Si-particles ranges from 0.5 to 0.8. The average diameters of the dendritic cells and the eutectic particles are about 10 μm and 2 μm, respectively. Furthermore, the quantitative analysis of the micrographs indicates a Si-particle area density of about 10%.

Table 1
Chemical composition of the Al–10Si–Mg–Mn high pressure die casting aluminum alloy

Element	Si	Mg	Mn	Fe	Ti
Weight %	10.3	0.09	0.58	0.12	0.07