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Through-process numerical simulations of the structural behaviour of Al–Si die-castings

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ABSTRACT

A through-process methodology for numerical predictions of the structural performance of thin-walled aluminium castings is presented. The methodology has been validated against experimental investigations of generic AlSi9MgMn components produced by high-pressure die-casting (HPDC). An experimental database consisting of both material tests and component tests has been established in a previous work [C. Dørum, H.I. Laukli, O.S. Hopperstad, M. Langseth, European Journal of Mechanics – A/Solids, in press, Available online: 18 April 2008]. Identification of critical defects has allowed for implicit reproduction of the defects by numerical casting process simulations of mould filling and solidification. Air/gas contact times have *per se* been considered numerically representative of the defects and have been semi-quantitatively transferred onto a finite element model for simulation of the structural behaviour of the cast components. Fracture of the cast aluminium alloy has been modelled using stochastic ductile fracture parameters; allowing for numerical prediction of the scatter in mechanical properties that are present in the cast material. The simulations using the proposed through-process methodology capture the scatter in mechanical properties found in HPDC material. The air/gas contact time criterion in the casting simulations appears to be a relevant measure to associate with the dominating flow-related defects found in die-castings. The controlling defects in the castings have been identified in previous studies as surface depressions, confluence welds and oxide bifilms. It is proposed that these defects are strongly correlated to the air/gas contact time criterion. The approach of using refined casting simulations and adopting the air/gas contact time criterion for defect mapping onto a FE mesh allows for numerical reproduction of the position-dependent scatter in mechanical properties found in HPDC components. The influence of the stochastic variations in local mechanical properties on the structural performance of cast components can be predicted by using stochastic fracture parameters.

1. Introduction

High-pressure die-casting (HPDC) is the most common shaped casting method. Die-castings are therefore used in many different applications from lids and covers to car components where the mechanical properties go beyond requirements of leak tightness. One market demand *per se*, is tailored HPDC alloys with excellent castability and attractive mechanical properties in T1-condition being capable of self-piercing-riveting joining and welding to steel and extruded aluminium. Additionally, it is often required that the HPDC alloys should withstand dynamic, or crash-relevant, loading situations. Obviously, this requires a fundamental understanding of the controlling factors for sufficient deformation behaviour, an area that has until now received little research attention.

Several defects, some of which are inherent to the HPDC process, play a role in the mechanical performance of die-castings. Macrosegregation of eutectic, intermetallic particles [2] and primary α-Al crystals [3], porosity [4], oxide bifilms [5] and confluence welds [6] are addressed as typical HPDC defects. It is not possible to point out a single defect controlling the mechanical performance. The works by Gokhale and Patel [7,8] on the mechanical properties of cast aluminium alloys showed that there was a strong quantitative correlation between the area fraction of defects and the tensile ductility. For a tilt-pour-permanent mould cast aluminium alloy the controlling defects were identified as oxide films and shrinkage pores, while for a semi-solid metal cast aluminium alloy the controlling defects were essentially residues of modifiers, fluxes, grain refiners and mould release agents. When looking at the attractive features of a HPDC microstructure, it is well known that a very fine-grained (grain size of less than 10 μm) and commonly defect-free surface layer is important for the mechanical

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properties. The surface layer, up to several hundred microns thick, forms due to the very high cooling rate in HPDC, being up to 1000 K/s [9].

Despite that the interpretation of defects on the HPDC mechanical behaviour still remains unexplored, the understanding of defect formation has matured significantly in recent years. Dilatant shear bands, in particular, have received major attention [10]. A premise for their formation is the presence of a mushy zone adjacent to the die wall. The dissipation of heat during HPDC processing is heat transfer controlled to the extent that the metal freezes at the die wall during die filling. The heat transfer coefficients (HTC) are not possible to measure directly, but can be calculated from temperature measurements and numerical modelling.

The main objective of this work is to develop design and modelling tools for the automotive industry that allow for a robust and reliable prediction of the structural behaviour of thin-walled cast components when subjected to static and dynamic loads, such as in crash situations. In the literature, several approaches based on through-process modelling for prediction of the structural behaviour of HPDC magnesium and aluminium components subjected to static and dynamic loads have been suggested, e.g. Ref. [11–13]. In this work, a novel method has been developed to virtually predict defects during HPDC and transfer the defects onto a finite element (FE) mesh for simulation of the structural behaviour of the cast component. Further, the use of stochastic fracture parameters allows for numerical prediction of the experimental scatter which is observed in mechanical tests. The simulations have been verified by studying experimentally produced AlSi9MgMn die-castings, thus providing a sound link between mechanical properties in generic castings and defects. The modelling approach presented here is considered as a first approximation being part of a through-process modelling framework for as-cast and naturally aged HPDC material (T1-condition).

2. Experimental data

All castings were produced with an AlSi9MgMn alloy with Hydro Aluminium's HPDC machine dedicated for aluminium alloy research, a Bühler shot-controlled development machine with a locking force of 4.1 MN. An illustration of a casting with gating system and vacuum channels is shown in Fig. 1a. The castings were produced without vacuum in this work. The casting has a generic U-shaped geometry with 2.5 mm thickness. Details of alloy and HPDC production parameters are provided elsewhere [14]. Fig. 1b shows for reference the typical microstructure of the AlSi9MgMn alloy in T1-condition.

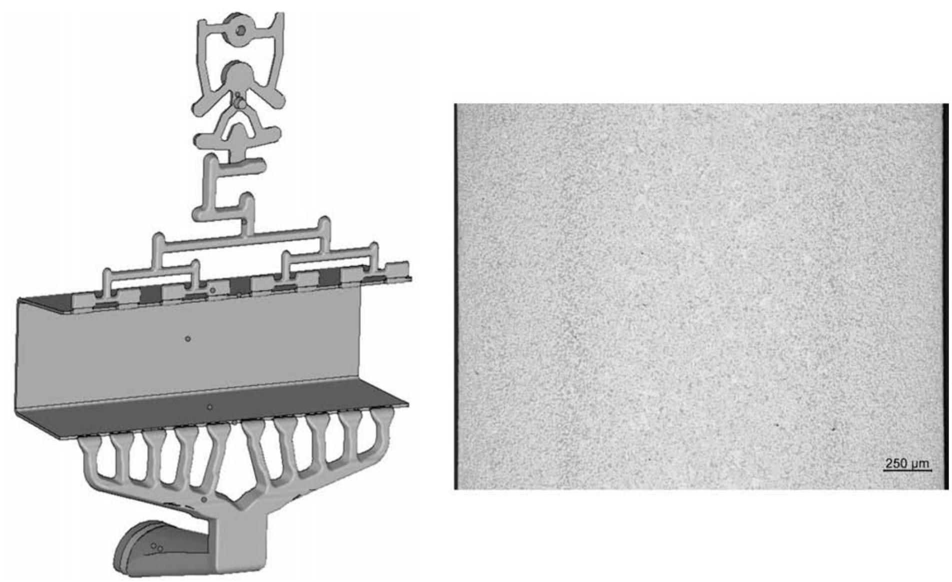

Fig. 1. (a) Illustration of U-profile casting with gating and vacuum channels. Length of U-profile: ~300 mm. Width: ~90 mm. Height: ~75 mm. Total casting: ~1300 g. (b) Typical AlSi9MgMn HPDC microstructure across the thickness, T1-condition, taken from the bottom flange of the casting. Darkest grey phase exhibits Al–Si eutectic.

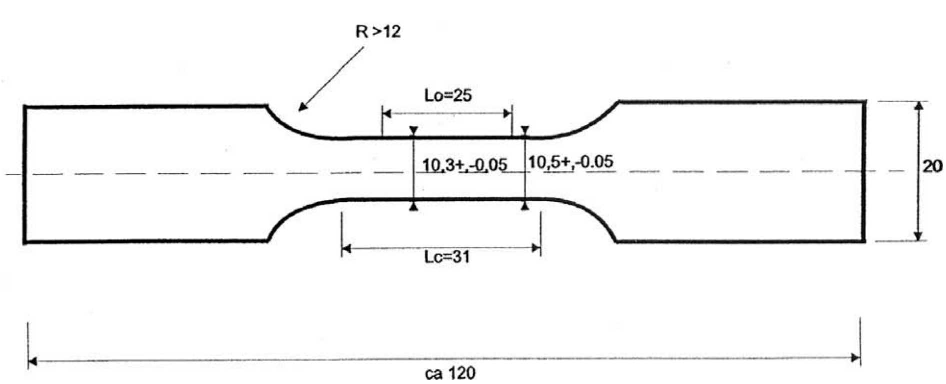

Fig. 2. Geometry of uniaxial tension test specimen [mm]. Picture is scaled from original.