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Numerical modelling of the structural behaviour of thin-walled cast magnesium components using a through-process approach

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Abstract

A through-process methodology for numerical simulations of the structural behaviour of thin-walled cast magnesium components is presented. The methodology consists of casting process simulations using MAGMAsoft, mapping of data from the process simulation onto a FE-mesh (shell elements) and numerical simulations using the explicit FE-code LS-DYNA. In this work, generic High Pressure Die Cast (HPDC) AM60 components have been studied using axial crushing, 3-point bending and 4-point bending tests. The experimental data are applied to obtain a validated methodology for finite element modelling of thin-walled cast components subjected to quasi-static loading. The cast magnesium alloy is modelled using a user-defined material model consisting of an elastic–plastic model based on a modified J2-flow theory and the Cockcroft–Latham fracture criterion. The fracture criterion is coupled with an element erosion algorithm available in LS-DYNA. The constitutive model and fracture criterion are calibrated both with data from material tests and data from the process simulation using MAGMAsoft.

Keywords: Casting; Mechanical; Defects

1. Introduction

As the lightest structural engineering metal available, magnesium is very attractive for structural automotive applications where weight saving is a matter of serious concern. With High Pressure Die Casting of magnesium and aluminium alloys, components with very complex, thin-walled geometry, like instrument panels, A and B pillars and front end structures, can be cast with a high production rate. The challenge with this production method is to optimize the process parameters with respect to the part design and the solidification characteristics of the alloy in order to obtain a sound casting without casting defects. Unbalanced filling and lack of thermal control can cause porosity and surface defects due to turbulence and solidification shrinkage. These defects can give low ductility compared to extruded materials, for instance. The HPDC method also leads to a "skin-effect", where the microstructure of the castings near the free surfaces differs significantly from the interior as the skin region has much finer microstructure [1,2].

Design and production of thin-walled cast structural components for the automotive industry are challenging tasks that involve the development of alloys and manufacturing processes, structural design and crashworthiness analysis. In order to reduce the lead time to develop a new product it is necessary to use finite element analysis to ensure a structural design that exploits the material. Accurate description of the material behaviour is essential to obtain reliable results from such analyses. In order to minimize the weight of the structural component while maintaining the safety in a crash situation, the ductility

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Nomenclature

W	fracture parameter in Cockcroft–Latham criterion	$\boldsymbol{\sigma}$	cauchy stress tensor
σ_1	maximum principal stress	$\boldsymbol{\varepsilon}$	true strain tensor
σ_e	von Mises stress	$\mathbf{C}$	elastic moduli
ε_e	equivalent plastic strain	$\mathbf{I}$	second order unit tensor
κ	reference work hardening	$\boldsymbol{I}$	fourth order unit tensor
		λ, μ	the Lamé constants

of the material has to be utilized without risking un-controlled failure. Hence, a reliable failure criterion is also required, giving limits for the plastic deformations under various loading combinations. Very precise and validated constitutive models and failure criteria are available for materials such as extruded aluminium and rolled steel [3]. However, much work is still to be done in this area for thin-walled cast materials.

The long-term objective of this work is to develop design and modelling tools that allow the structural behaviour of thin-walled cast components to be predicted when subjected to static and dynamic loads. In the current study, the structural behaviour of generic structural HPDC components, shown in Figs. 1 and 2, has been investigated using axial crushing, 3- point bending and 4-point bending tests.

The components were cast of magnesium alloy AM60 at Hydro's Research Centre in Porsgrunn, Norway with a Bühler SC42D 420-ton cold chamber die casting machine.

2. Material characterization

The first step in the development of the through process strategy for numerical modelling of thin-walled castings is material characterization. For the case of high pressure die-cast Mg alloys, the microstructure of the castings usually contains a fine-grained "skin" with a microstructure significantly different from the bulk material. In this work, the overall work hardening properties have been characterized using uniaxial tensile specimens cut from the 80 mm wide flange of the generic AM60 components without ribs illustrated in Fig. 1. The specimens were aligned with the longitudinal direction of the components. Contrary to what is observed with extruded aluminium alloys, the test specimens were found to fail before the point of diffuse necking.

The AM60 material has also been characterized using uniaxial compression tests, since previous work [3–5] revealed different tensile and compressive behaviour for magnesium alloys. For details, it is referred to Dørum et al. [6]. The experimental true stress–true plastic strain curves for both uniaxial tension and uniaxial compression are shown in Fig. 3. By comparing the stress–strain curves obtained from tensile test specimens cut from different positions in the cast AM60 component, no significant differences were found regarding the observed stress level. Therefore, the stress–strain curves given in Fig. 3 can be viewed as representative for the overall work hardening properties.

Since the tensile tests [7] did reveal very small differences in stress level, it is assumed that the hardening properties are uniform throughout the component. The tensile yield stresses (0.2% proof stress) were typically in the range 122 ± 3 MPa. Further, assuming that the fracture in the tensile tests starts in the interior material, the tensile ductility of the interior material is also characterized using these

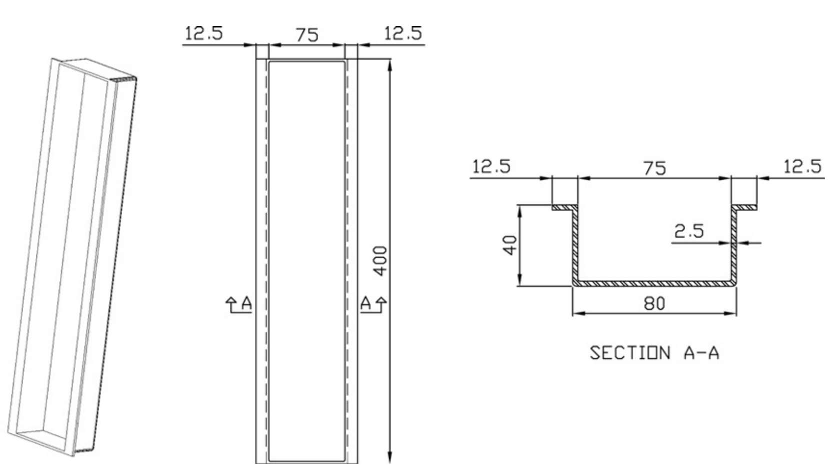

Fig. 1. Generic profile geometry of cast AM60 component without ribs.