European Journal of Mechanics A/Solids 28 (2009) 1–13

Contents lists available at ScienceDirect

European Journal of Mechanics A/Solids

www.elsevier.com/locate/ejmsol

Structural behaviour of Al–Si die-castings: Experiments and numerical simulations

C. Dørum [a,c,*], H.I. Laukli [b,c], O.S. Hopperstad [c], M. Langseth [c]

[a] *SINTEF Materials and Chemistry, Trondheim, Norway*
[b] *Hydro Aluminium Metal, Research & Technology Development, Sunndalsøra, Norway*
[c] *Structural Impact Laboratory (SIMLab), Centre for Research-based Innovation, Trondheim, Norway*

ARTICLE INFO

Article history:
Received 22 May 2007
Accepted 25 March 2008
Available online 18 April 2008

Keywords:
High-pressure die-casting (HPDC)
Al–Si foundry alloys
Finite element analysis
Fracture

ABSTRACT

Axial crushing and three-point bending tests have been performed in order to establish an experimental database of the behaviour of generic high-pressure die-cast (HPDC) Al–Si alloys. The experimental data are used to obtain a validated methodology for finite element modelling of thin-walled cast components subjected to quasi-static loading. The HPDC structural components are modelled in the non-linear explicit FE-code LS-DYNA using shell elements. The behaviour of the cast aluminium alloys are described using the classical J_2 flow theory and the Cockcroft–Latham fracture criterion, which is coupled with an element erosion algorithm available in LS-DYNA. The comparison of the experimental and predicted behaviours of HPDC components gives promising results. The use of the fracture criterion of Cockcroft and Latham seems to be an effective approach to predict failure in HPDC components. A novel modelling approach is outlined accounting for different material properties through the thickness, thus incorporating the effects of a fine-grained surface layer and a central region that possesses lower ductility.

1. Introduction

The use of high-pressure die-castings (HPDC) made of aluminium alloys is no longer limited to applications such as fittings and housings. The casting process and the aluminium alloys have reached a level of quality that makes manufacturing of structural components possible. However, this requires careful control of the casting process, melt quality and a correct selection of aluminium alloys. A commonly used aluminium alloy for HPDC automotive components is AlSi9Mg. The requirements for high ductility in chassis components are stringent, and a cost and time consuming solution heat treatment is often required for this type of alloys. The ductility of Al–Si castings is largely governed by the volume fraction of Al–Si eutectic and it is therefore advantageous to reduce the Si content. A reduction in the amount of Si is feasible without significantly affecting the castability. Fig. 1 shows the typical HPDC microstructure of an AlSi4Mg alloy. This alloy contains approximately 20% Al–Si eutectic in contrast to AlSi9Mg that contains about 80%, as estimated by the Alstruc solidification model (Dons et al., 1999). Therefore, the AlSi4Mg alloy gives much better ductility in the as-cast condition (Cosse et al., 2003). In addition, some microstructural features that are inherent to the HPDC process control the ductility in the die-castings. It is widely accepted that a fine-grained, defect-free surface layer is a requisite for obtaining good ductility in thin-walled HPDC aluminium alloys. Furthermore,

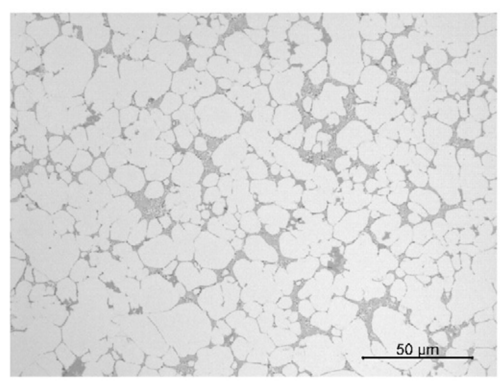

Fig. 1. Typical microstructure of an HPDC AlSi4Mg alloy. The primary α-Al crystals appear with light grey tone, while the Al–Si eutectic appears darker. Some Fe-, Mn-bearing intermetallic particles are present with approximately similar grey-tone as the eutectic.

the central region, or core, that contains macro-segregation of Al–Si eutectic in the form of bands that follow the surface contour of the casting (Laukli et al., 2005a) and a mixture of externally solidified crystals (ESCs) and fine grains (Laukli et al., 2005b), affects the properties. The segregation bands form from deformation of the mushy zone adjacent to the die wall during the HPDC process and dilatation that results in localisation of segregated liquid (Gourlay and Dahle, 2007).

This article develops engineering design and modelling tools that allow the structural behaviour of thin-walled cast aluminium

* Corresponding author.
E-mail address: cato.dorum@bygg.ntnu.no (C. Dørum).

0997-7538/$ – see front matter
doi:10.1016/j.euromechsol.2008.03.004

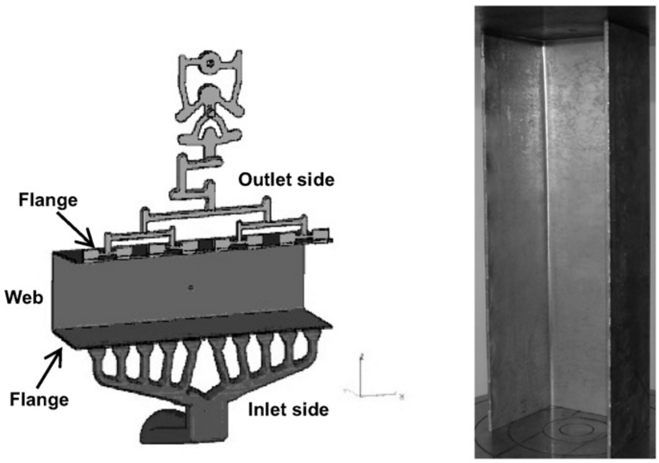

Fig. 2. Left: Illustration of the generic HPDC U-profile with length of 300 mm and thickness of about 2.5 mm and corresponding gating system. Right: Picture of casting in axial crushing rig.

Table 1
Alloy compositions [wt%]

Alloy	Si	Mg	Mn	Fe
AlSi4Mg	4.3	0.19	0.70	0.15
AlSi9Mg	9.0	0.23	0.85	0.17

components to be predicted under static and dynamic loading conditions. Here, it has been chosen to model the observed behaviour using relatively simple models. The results from this work can then serve as a basis for development of more sophisticated models at a later stage. When using HPDC aluminium alloys in structural applications, it is a requisite to understand the influence of the microstructural features on the structural behaviour. Therefore, to obtain a realistic model of the structural behaviour of HPDC components, a correct interpretation of defects must be applied. Thin-walled HPDC U-profiles made of the AlSi4Mg and AlSi9Mg alloys are investigated in the present study. The material behaviour is examined using uniaxial tension tests, notched specimen tests providing near plane-strain condition, shear tests, and plate-bending tests. In addition, axial crushing and three-point bending tests of the components are performed. Only quasi-static loading conditions are considered in the material and component test programmes. The experimental data are applied to obtain a validated methodology for finite element modelling of thin-walled aluminium castings, using shell elements, the J_2 flow theory and the Cockcroft–Latham ductile fracture criterion. Shear fracture (due to shear band localisation) has not been accounted for in the present work.

2. Material tests

Fig. 2 shows the geometry of the AlSi4Mg and AlSi9Mg U-profiles investigated in this study, together with the corresponding gating system. The castings were produced in a well-controlled manner with a shot controlled cold chamber high-pressure die-casting machine at Hydro's Research Centre in Porsgrunn, Norway. The length of the U-profile is 300 mm and the wall thickness is approximately 2.5 mm. The gate velocity was 47 m/s, the filling time was approximately 20 ms and the nominal feeding pressure was 60 MPa. Table 1 shows the alloy compositions.

Material tests were carried out to characterise the materials and on this basis identify the material parameters. Standard quasi-static uniaxial tensile tests were conducted to calibrate the yield criterion, the work-hardening parameters and to investigate the

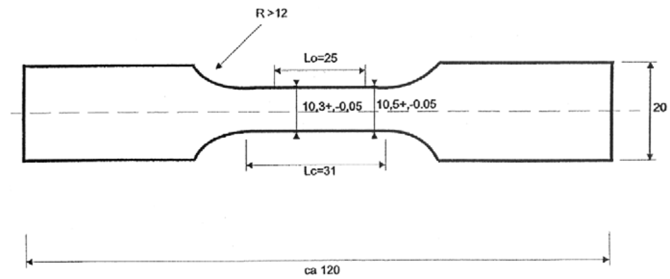

Fig. 3. Geometry of tension test specimen [mm]. Picture is scaled from original.

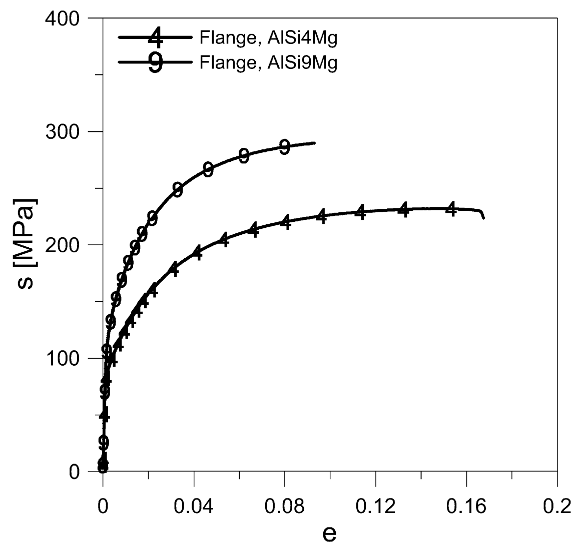

Fig. 4. Typical engineering stress–strain curves obtained from uniaxial tensile tests of AlSi4Mg and AlSi9Mg.

tensile ductility for the interior material. In addition, notched tension tests providing near-plane strain conditions and shear tests were performed. Finally, bending tests of plates cut from the cast U-profiles were carried out to investigate the ductility of the surface material. All of the material tests were carried out at room temperature in T1 condition. It should be noted that the AlSi9Mg alloy usually is subjected to heat treatment before use in the automotive industry.

2.1. Uniaxial tension tests

Uniaxial tension test specimens were machined from the wide web of the cast U-profiles shown in Fig. 2. The specimens were aligned with the longitudinal direction of the AlSi4Mg and AlSi9Mg components. The geometry of the tensile specimens is shown in Fig. 3.

The tests were carried out in an Instron materials testing machine. The tests were performed under displacement control, with a rate of displacement starting at 2 mm/min and increasing to 5–8 mm/min after 2% elongation, giving a strain rate of approximately 2×10^{-3} s^{-1}. The strain in the length direction was measured by an Instron clip-on, one-sided extensometer with 25 mm gauge length.

Typical experimental engineering stress-strain curves for the AlSi4Mg and AlSi9Mg castings are shown in Fig. 4. Note the different yield strength, work hardening and fracture elongations of the two alloys. As expected in T1 condition, most of the test specimens were found to fail before the point of diffuse necking. Furthermore, larger scatter is observed for the aluminium castings than what is typically found for rolled and extruded aluminium alloys. Pictures of the fractured specimens are provided in Fig. 5 for AlSi4Mg