



Effect of chemical compositions on tensile behaviors of high pressure die-casting alloys Al-10Si-yCu-xMn-zFe

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ABSTRACT

Effects of chemical compositions on the tensile properties, deformation behavior and fracture mechanism have been studied in a die-casting aluminum alloys Al-10Si-yCu-xMn-zFe. The test specimens were taken from the engine support brackets and tested at 20 °C, 150 °C and 300 °C. Addition of Mn and Cu elements in the Al-10Si alloys can significantly increase the YS and UTS of the alloys. The as-cast Al-10Si-1.5Cu-0.8Mn-0.15Fe alloy exhibits the highest tensile properties (RT: YS of 190 MPa and UTS of 308 MPa, 150 °C: YS of 176 MPa and UTS of 249 MPa, 300 °C: YS of 94 MPa and UTS of 111 MPa). Increasing test temperature reduces the YS and UTS and improves the ductility of the alloys. Chemical compositions (such as Mn, Cu and Fe) do not significantly affect the work-hardening behavior of the alloys. Increasing test temperature significantly decreases the n and k values. Phase particles (both Si and (Fe/Mn)-rich) cracking and debonding determine the fracture mechanism of the alloys. Final failure of the alloys mainly depends on the global instability (HT, necking) and local instability (RT, shearing).

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1. Introduction

Cast aluminum alloy are increasingly used in automotive, aerospace and other transportation industries for light weighting and better performance [1–3]. Among various kinds of casting process, high pressure die casting (HPDC) is more suitable for mass production due to its higher productive efficiency, capacity of producing intricate shapes and thin-walled components, good dimensional accuracy and surface finish, and good mechanical properties [4–6]. Due to high filling speed and fast cooling rate, however, the gases have no enough time to escape from the cavity. As a consequence, these gases in cavity are inevitably involved in the metal liquid, leading to casting defects such as pores and oxide inclusions forming in the components [7–10]. During fatigue testing, these defects serve as stress concentration sites for fatigue crack initiation, resulting in lower fatigue properties of these castings [6,11,12]. In addition, at the elevated temperature environment, the gases in the pores are easy to dilate, which causes the surfaces of the castings to bubble. This result significantly influences the appearance quality of the products and deteriorates the mechanical properties of the castings. For casting aluminum alloys, heat treatment has been recognized as one of the most

important factors in improving the mechanical performance [13–15]. For the large castings with thin wall, however, it is necessary to carry out the rectification works after heat treatment. This is attributed to the changes in size for these components after solution treatment and aging treatment. Therefore, it would have more interesting to develop new die cast aluminum alloys which do without heat treatment and also provide higher mechanical properties so as to widen practical applications of cast aluminum alloys.

Besides reasonable component structure and perfect design mold, the alloy selected for high pressure die casting is also one of the most important elements to obtain excellent die cast productions [16–18]. The new developed alloys with excellent fluidity, narrow range of crystallization temperature and better mechanical properties as well as corrosion resistance are very attractive for larger and complicated castings with thin wall. More importantly, the mechanical properties of the alloys without experiencing heat treatment also can meet the requirements for the productions. In order to improve the formability, mechanical strength and ductility of Al-10Si alloys, chemical compositions of the alloys applied in this work were designed as follow: (1) it is commonly accepted that Fe content is above 0.8% (all composition in wt% except otherwise stated), the molten metal has little or no tendency to dissolve and solder die steel [19]. In contrast, high Fe content tends to form a large number of brittle intermetallic compounds [20–23]. These brittle particles significantly deteriorate the mechanical

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properties of the castings. In order to avoid its negative effect, Fe content is reduced to as low as 0.15–0.25%; (2) the main effect of manganese (Mn) (0.2–0.8%) added into Al–Si alloy is to replace the iron (Fe) and prevent the die-sticking [19]; (3) besides the copper (Cu) content (0.5–1.5%) and magnesium (Mg) content (0.25–0.3%), some other impurity elements (i.e. Zn) are strictly controlled in low level ($< 0.02\%$). RE (rare earth) ($< 0.1\%$) are used to reduce the oxide inclusions and purify the microstructure of the alloys [24–26]. Since many structural applications involve high stress and high temperature, the plastic deformation and tensile properties of aluminum alloys are critical for their design and manufacturing [27–31]. The present study was conducted to investigate the effects of chemical compositions on the tensile properties, the plastic deformation behaviors and the fracture mechanisms of the as-cast Al–10Si–yCu–xMn–zFe aluminum alloys (engine support bracket) (both room temperature (RT) and high temperature (HT)) so as to widen practical applications of these new die casting alloys.

2. Experimental procedure

2.1. Material and sample preparation

High pressure die castings of the Al–10Si–yCu–xMn–zFe alloys used as the study objects, as shown in Fig. 1a, were obtained by using a LK400S 4000kN HPDC machine. The alloys with a nominal composition of Al–10Si–0.5Cu–xMn–0.15Fe ($x=0.2, 0.4, 0.6$, and 0.8 ; designated as Group-1 alloy: A₁, A₂, A₃ and A₄, respectively), Al–10Si–yCu–0.8Mn–0.15Fe ($y=0.5, 1.0$, and 1.5 ; designated as Group-2 alloy: B₁, B₂ and B₃, respectively), and Al–10Si–1.5Cu–0.8Mn–zFe ($z=0.15$ and 0.25 ; designated as Group-3 alloy: C₁ and C₂, respectively) were, respectively, prepared from high purity Al, Al–8Si, Al–50Cu, Al–10Mn, Al–10Ti and Al–10RE master alloys in an electrical resistance furnace, and then cast into a metal mold at pouring temperature of 690–700 °C and mold temperature of 180–200 °C. Before pouring, the melt was held in the furnace at 690 ± 3 °C for 30 min to ensure homogeneity and dissolution of the present intermetallic. Die casting parameters including filling speed (mm/s) and filling time (s) at different stages are shown in Fig. 2. The actual composition was measured by an Optima 7300DV inductively coupled plasma optical emission spectroscopy (ICP-OES) and shown in Table 1. Tensile specimens used in this work were taken from the plate shaped part of the die castings, as shown in Fig. 1b. Tensile samples were cut into rectangular tensile specimens with dimensions of 6 mm width, 6 mm thickness and 25 mm gauge length by an electric-sparking wire-cutting machine [32]. The gage surfaces of all tensile specimens were polished parallel to the specimen axis using paper of grit 1600 to avoid the

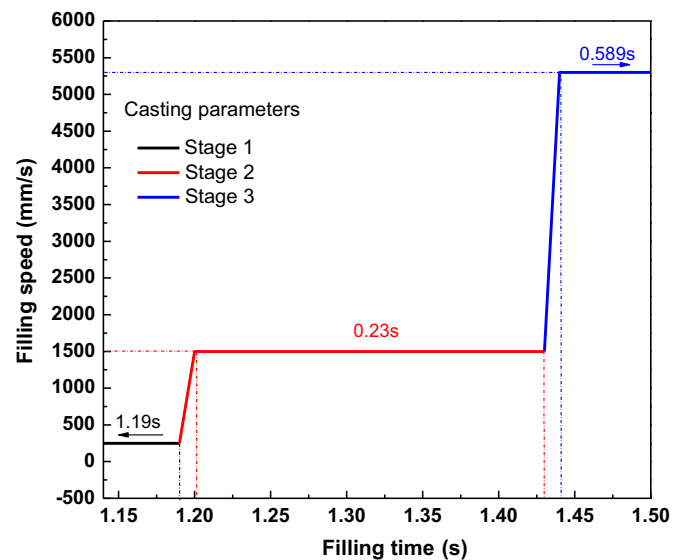


Fig. 2. Die casting parameters including filling speed (mm/s) and filling time (s) at different stages.

influence of machining on the tensile results. In this study, all tensile samples were kept at room temperature for three days before testing their tensile properties.

2.2. Tensile testing

Tensile testing was performed on a Zwick/Roell-20kN tensile machine with an attached high temperature furnace controlled within ± 3 °C. Stress-strain curves were obtained by attaching a knife-edge extensometer (25 μm) to the gauge section of the specimens. The ultimate tensile strength (UTS), 0.2% proof stress (YS), and elongation (A) of the specimens were determined from the test data. Three test temperatures including 20 °C, 150 °C, and 300 °C were applied to investigate the effect of the chemical composition and test temperature on the tensile properties, deformation behavior and fracture mechanism of the alloys under different test temperatures. Tensile samples were first heated to the desired temperature and held at the test temperature for 15 min, and then tested at a strain rate of $6.67 \times 10^{-4} \text{ s}^{-1}$. At least four tensile tests were finished for each chemical composition and each test temperature.

2.3. Fractographic analysis & microstructural

The fracture surfaces of the tensile specimens were investigated using a JEOL JSM–6460 field emission scanning

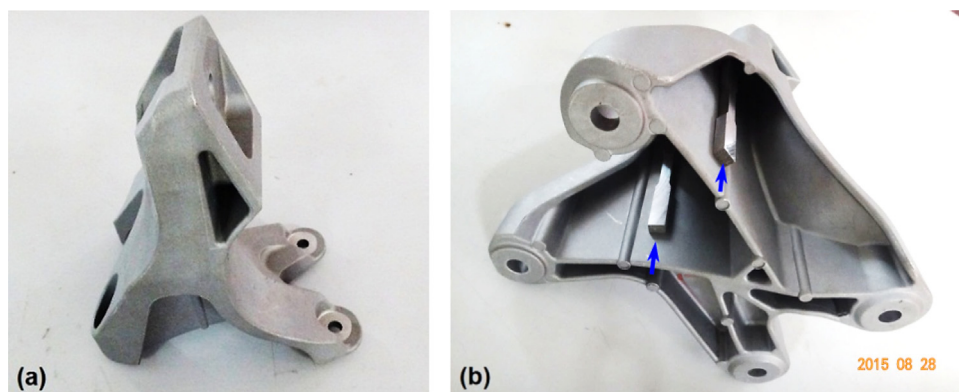


Fig. 1. (a) Al–10Si–yCu–xMn–zFe alloys castings and (b) tensile sampling positions.

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