Materials and Design 32 (2011) 3900–3910

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Impact toughness and fractography of Al–Si–Cu–Mg base alloys

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ARTICLE INFO

Article history:
Received 18 October 2010
Accepted 27 February 2011
Available online 21 March 2011

Keywords:
A. Non-ferrous metals and alloys
E. Mechanical
G. Fractography

ABSTRACT

Critical automotive applications using heat-treatable alloys are designed for high impact toughness which can be improved using a specified heat treatment. The alloy toughness and fracture behavior are influenced by the alloy composition and the solidification conditions applied. The mechanical properties of alloys containing Cu and Mg can also be enhanced through heat treatment. The present study was undertaken to investigate the effects of Mg content, aging and cooling rate on the impact toughness and fractography of both non-modified and Sr-modified Al–Si–Cu–Mg base alloys. Castings were prepared from both experimental and industrial 319 alloy melts containing 0–0.6wt% Mg. Test bars were cast in two different cooling rate molds, a star-like permanent mold and an L-shaped permanent mold, with dendrite arm spacing (DAS) values of 24 and 50 μm, respectively. Test bars were aged at 180 °C and 220 °C for 2–48 h. Charpy Impact test was used to provide the impact energy. It was observed that high cooling rates improve the impact toughness whereas the presence of Cu significantly lowers the impact properties which are determined mainly by the Al_2Cu phase and not by the eutectic Si particles. The addition of Mg and Sr were also seen to decrease the impact toughness. The crack initiation energy in these alloys is greater than the crack propagation energy, reflecting the high ductility of Al–Si–Cu–Mg base alloys.

1. Introduction

Aluminum–silicon casting alloys are used for automotive applications, owing to their high strength-to-weight ratio and ability to be cast into complex shapes. The Al–Si–Cu alloy group is popular in such applications where magnesium additions further harden the alloy. Under normal cooling conditions, eutectic Si particles, present as coarse acicular needles, act as crack initiators, thereby lowering the mechanical properties. The addition of small amounts of Sr to the melt alters the acicular morphology of these Si particles to a fibrous one, which brings about a great improvement in the mechanical properties [1]. Silicon particle characteristics can also be affected through thermal modification by subjecting the casting to a high temperature treatment for extended periods. These two types of modification have been used together to produce the desired properties in the casting. Modification, if combined with heat treatment, brings about significant improvements in impact strength, which can lead to increases of several hundred percent [1–3].

The initial strength of the Al–Si alloy may be enhanced by the addition of alloying elements such as copper, magnesium and strontium [1,4]. The improvement in the properties of Al–Si–Cu alloys is primarily due to the precipitation of Al_2Cu within the alloy matrix during aging. Changes in the morphology of Si during solution treatment also contribute to an improvement in the alloy properties. When the brittle Al_2Cu phase is present, fracture is no longer controlled by the Si particles. Although the eutectic Si has been Sr-modified, the impact strength does not improve. Moreover, there is a tendency to form more block-like Al_2Cu, which does not dissolve during heat treatment, in the presence of Sr, which contributes to the noticeably low impact strengths in 319 alloys [1,4–7]. According to Paray et al. [3], Al–Si foundry alloys containing Cu have poor impact properties; the presence of the copper contributes significantly to lowering impact properties; and the fracture behavior is influenced by undissolved Cu-phases and no longer by the Si particles.

The addition of Mg can bring about the segregation of the Al_2Cu phase, rendering it more difficult to dissolve during solution heat treatment. Additions of up to 0.5wt% Mg can lead to a marked increase in the volume fraction of the Cu-containing phase [3,8–10]. Several authors [4,11] reported that both Mg and Sr can lead to severe segregation of Al_2Cu in 319.2 alloys, resulting in the formation of large amounts of the coarse block-like phase, compared to its finer eutectic-like form. These segregated block-like Cu-rich phase particles decreased the impact strength of the 319 alloys [3,9]. The present work was undertaken to investigate the effects of Mg content, aging conditions, and cooling rate on the impact toughness and fracture behavior of Al–Si–Cu–Mg base alloys.

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doi:10.1016/j.matdes.2011.02.058