Materials Science & Engineering A 559 (2013) 496–505

Contents lists available at SciVerse ScienceDirect

Materials Science & Engineering A

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

Effect of T6 heat treatment on the defect susceptibility of fatigue properties to microporosity variations in a low-pressure die-cast A356 alloy

Choong do Lee *

Department of Metallurgical & Materials Engineering, Inha Technical College, 253, Younhyun-dong, Nam-gu, Incheon 402-752, South Korea

ARTICLE INFO

Article history:
Received 13 June 2012
Received in revised form
3 August 2012
Accepted 27 August 2012
Available online 1 September 2012

Keywords:
A356 Alloy
Low-pressure die casting
Microporosity
Fatigue properties
Defect susceptibility
T6 heat treatment

ABSTRACT

The present study aimed to optimize the conditions for the T6 heat treatment of low-pressure die-cast A356 alloy in terms of the dependence of fatigue properties on microporosity variation. The fatigue property was evaluated using a high cycle fatigue test, and the microporosity was based on the fractographic porosity measured through SEM imaging of a fractured surface. The number of cycles to failure for the A356 alloy depends on the variations in microporosity through an exponential relationship. Because the fatigue strength coefficient and exponent of the *S–N* curve is always underestimated in the presence of microvoids, the evaluation of the number of cycles to failure achievable in a defect-free condition has practical significance. Detailed suggestions for improving the number of cycles to failure were accomplished based on the modified Basquin's equation, which fundamentally determines the number of cycles to failure from both the defect susceptibility of the tensile strength and the maximum achievable tensile strength in a defect-free environment. A T6 heat treatment with solutionizing and aging treatment times of 6 h at 540 °C and 16 h at 160 °C, respectively, is proposed as the optimal conditions for improving the number of cycles of A356 alloy at stress amplitudes of less than 200 MPa.

1. Introduction

A356 alloy is a typical Al–Si series alloy that is widely used in automotive components such as engine and chassis parts that are usually fabricated through various casting processes and post-heat treatments. Additionally, the precipitation hardenability of A356 upon heat treatment combined with both excellent castability and specific strength make this alloy a premium material for effectively addressing environmental problems involving energy efficiency through weight reduction. Manufacturing thin-walled and integrated-section components through the casting process has been recommended as a practical way to maximize weight efficiency and decrease costs.

However, the formation of casting defects such as micropores and microvoids is unavoidable during conventional casting processes and plays a decisive role in restricting design freedom because such defects degrade the mechanical properties of the castings and introduce wide deviations in quality. Therefore, many experimental and theoretical studies have been conducted to evaluate the effects of these internal discontinuities on the mechanical properties of castings, e.g., tensile properties [1–7] and fatigue properties [8–14].

For example, Ammar et al. reported that the fatigue properties of aluminum alloys depend primarily on the distribution and size of microvoids [11,12]. Additionally, Wang et al. reported that the number of cycles to failure depends more on the existence of microvoids than oxide inclusions, and this dependence is proportional to the square-root of the microvoid size, as indicated by the increasing slope of the correlation between void size and number of cycles to failure [14]. These results suggest that the relationship between fatigue properties and microporosity can be quantitatively described in terms of the susceptibility of fatigue properties to microporosity variation.

However, it is well-known that the mechanical properties of heat-treatable aluminum alloys vary markedly based on the solution treatment and artificial aging conditions during T6 treatment [15]. In terms of the defect susceptibility of the tensile properties to microporosity variations, we suggested the optimal T6 treatment conditions for minimizing defect susceptibility [16]. Based on these rules, the variations in the defect susceptibility of the tensile properties after T6 treatment is intimately related to the dependence of fatigue properties on microporosity variations, and an empirical relationship was suggested as a practical description in our previous study [17].

The present study aims to optimize the T6 treatment conditions to minimize the defect susceptibility of the cycles to failure due to microporosity variations in low-pressure die-cast A356 alloys and investigate the practical contribution of these defect

* Tel.: +82 32 870 2181; fax: +82 32 520 4923.
E-mail address: cdlee@inhatc.ac.kr

0921-5093/$ - see front matter
http://dx.doi.org/10.1016/j.msea.2012.08.131

susceptibilities and microporosity variations to Basquin's relation for high-cycle fatigue properties.

2. Experimental procedure

2.1. Specimen preparation and microstructure observation

The raw material used in the present study was commercially available A356 alloys, and the test specimens were obtained from low-pressure die-casting process in the form of an automobile wheel (diameter: 18 in., 5-spokes). And, the chemical composition of this alloy is listed in Table 1.

The tensile and fatigue specimens were prepared from a position perpendicular to the circumference of the rim, and the specimen for microstructure observation was obtained from a position neighbor to the gauge section of tensile specimen. The position for preparation of each specimen is shown in Fig. 1.

The test specimens were prepared using as-cast and T6 treatment conditions, and the details of the T6 treatment are listed in Table 2. The solution treatment was performed for 3, 6 or 12 h at 540 °C, and the artificial aging was conducted for 48 h at 160 °C.

The microstructure observation was conducted on as-cast alloys and several T6-treated alloys that were aged for 16 h for each solution treatment condition. The etchant used was Keller solution (2% HF+3% HCl+5% HNO_3+dist. water). The area fraction of the eutectic Si-particles was measured using a 2-color contrast image analyzer, and the secondary dendrite arm spacing (SDAS) was measured using the intercept method.

Table 1
Chemical composition of A356 aluminum alloy.

Elements	Si	Mg	Mn	Cu	Fe	Ti	Sr	Al
Composition (wt%)	7.42	0.372	0.015	0.14	0.272	0.14	0.02	Bal.

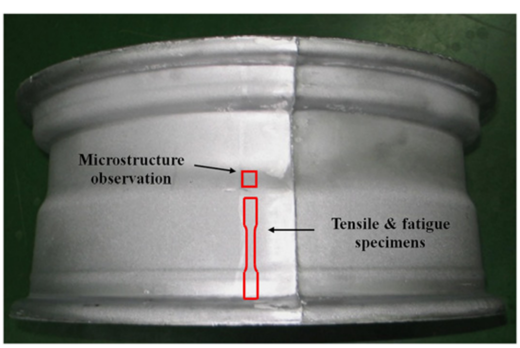

Fig. 1. Schematic diagram for specimen preparation in rim section of automotive wheel.

Table 2
Detailed conditions for the solution treatment and artificial aging during T6 treatment.

Detail condition	Heat treatment			
	Solution treatment		Artificial aging	
	Temperature (°C)	Time (h)	Temperature (°C)	Time (h)
Contribution of solution treatment	540	3/6/12	160	16
Contribution of artificial aging	540	6	160	4/16/48

2.2. Microporosity measurement and tension test

The microporosity of the test specimens was measured by quantitative fractography of surfaces fractured during the tensile and fatigue tests. These quantitative fractographic analyses involved the examination of SEM images of the fractured test specimen surfaces, with porosity expressed in terms of the ratio of the microvoid area to the entire area of the fractured surface. The tensile specimen was a plate type with a gauge length and width of 30 and 6 mm, respectively, and it was fabricated more than six pieces for as-cast and each T6-treatment condition. The tension test was performed at room temperature with a strain rate of 2.78×10^{-4} /s as measured with an extensometer.

2.3. High-cycle fatigue test

The high-cycle fatigue test was conducted according to the ASTM E466 test procedure specifications with sinusoidal loading using an Instron model 5585 at room temperature [18]. The fatigue test was performed using a stress ratio of $R=-1$ with frequency of 20 Hz. The nominal stress amplitude was 130–180 MPa for as-cast alloy and 160, 200 or 240 MPa for T6-treated alloys.

Each specimen was fabricated as a standard test type with a gauge length and diameter of 15 and 5 mm, respectively. The surface of each test specimen was also carefully prepared using SiC emery paper (~#2000) to remove any mechanical notches that may have formed during the machining of the test specimen surface.

The number of test specimens was more than six pieces for a given stress amplitude, and the experimental result was restricted to the specimen that required more than 100 cycles prior to failure. And, the fatigue strength coefficient and exponent in Basquin's equation were obtained via regression analysis of the experimental data using a least-squares method. The fatigue strength coefficient was taken by intercept of the log(stress amplitude, $\Delta\sigma/2$) vs. log($2N_f$) plot at $2N=1$, and the fatigue strength exponent was obtained from the slope of log(stress amplitude) vs. log($2N_f$) [19,20].

3. Results

3.1. Variations in the microstructural characteristics and tensile properties after T6 treatment

Fig. 2 presents the variations in the area fraction of the eutectic Si particles and SDAS upon the solution treatment of the specimens, which were artificially aged for 16 h at 160 °C, relative to the as-cast specimens. The area fraction of the eutectic Si particles decreased markedly from 21.7% in the as-cast samples to 11.2% with a solutionizing time of 12 h. These results indicate that the SDAS gradually increased from 42 μm to 46 μm via the dissolution of the eutectic Si particles on solution treatment. Additionally, these tests verified that the artificial aging caused slight variations in the area fractions of eutectic Si particles and SDAS related to the solution treatment.

Fig. 3 illustrates the overall trends in the variation of the tensile properties upon completion of the (a) solutionizing and (b) artificial aging periods. Under the same artificial aging conditions (160 °C/16 h), the solution treatment slightly increased both the yield strength (from 228 to 233 MPa) and the tensile strength (from 291 to 297 MPa). However, it exhibits that the tensile strengths are remarkably enhanced by T6-treatment, comparing with those of as-cast specimen.