Materials Science and Engineering A 468–470 (2007) 171–175

MATERIALS SCIENCE & ENGINEERING A

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Effects of laser peening treatment on high cycle fatigue properties of degassing-processed cast aluminum alloy

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Received 10 March 2006; received in revised form 7 May 2006; accepted 6 September 2006

Abstract

It is well known that the degassing (DG) process is very useful for reducing cast defects such as porosities, micro-shrinkages, and inclusions in metallic alloy casting processes. The authors had previously clarified that DG processing is an effective method for improving the fatigue property of cast aluminum alloy. In this study, a treatment involving laser peening without coating (LPwC) was applied to the DG process cast aluminum alloy with an aim to further improve the fatigue property of the alloy. Fatigue tests under rotating bending were carried out on the LPwC-treated DG process cast aluminum alloy in order to investigate the effects of the LPwC treatment on fatigue properties such as fatigue strength, crack initiation, and propagation behavior. From the results, it was found that the fatigue life and fatigue strength at 10^7 cycles of the DG process cast aluminum alloy improved by the LPwC treatment. The possible reason for this improvement is the deceleration of the surface crack growth rate due to the compressive residual stress in the surface layer induced by the LPwC treatment.

Keywords: Laser peening; Degassing process; High cycle fatigue; Residual stress

1. Introduction

Cast aluminum alloys have been widely used for automobile parts and other manufactured parts because they facilitate a reduction in weight, formability, and cost [1–5]. However, it may be difficult to use these alloys for parts that require a high fatigue strength and high reliability because a large number of casting defects exist in them. The authors have reported that the degassing process (DG) is useful for decreasing the casting defects in cast aluminum alloys and for improving the fatigue strength [6]. The authors have also reported that the fatigue strength of the degassing process cast aluminum alloy can be improved by shot peening treatment [7].

In this study, we focus our attention on a treatment involving laser peening without coating (LPwC) [8]; by this method, it is possible to introduce higher compressive residual stresses on the surface of the material than by shot peening. Laser shock peening (LSP) treatment with surface coating has been successfully applied to enhance the fatigue properties of high strength aluminum alloys used in aerospace structures [9,10]. However, there are few reports on the application of the LPwC treatment to the cast aluminum alloys used in automobile structures [11,12]. In the previous report, we cleared that the residual stress of the LPwC treated AC4CH material could be estimated by fatigue crack propagation behavior [12].

The objective of this study is to investigate the effect of the LPwC treatment on the high cycle fatigue properties of AC4CH cast aluminum alloy. Further, fatigue tests under rotating bending are carried out and the surface fatigue cracks are observed. And then, fatigue property improvement is discussed with compressive residual stress to be based on the results of previous report [12].

2. Experimental procedure

2.1. Material and specimens

The material used in this study was the DG process AC4CH cast aluminum alloy, which is an Al-Si-Mg alloy with the chemical composition shown in Table 1. The DG process was carried out as follows. After melting the AC4CH ingot, argon gas was blown into the molten metal. As a result, the argon gas surfaced

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0921-5093/$ – see front matter
doi:10.1016/j.msea.2006.09.126

Table 1
Chemical compositions of the material in mass%

	Cu	Si	Mg	Zn	Fe	Mn
AC4CH	0.032	6.92	0.307	0.009	0.158	0.007

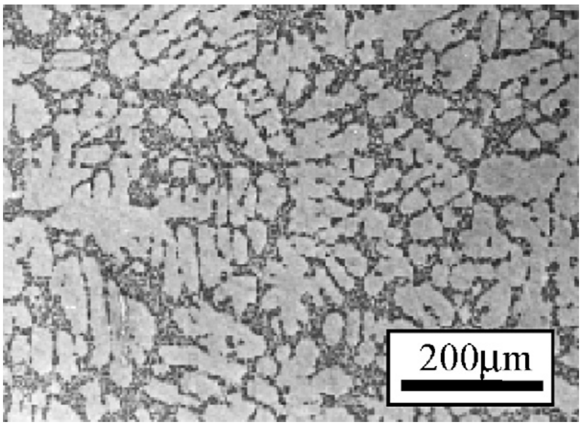


Fig. 1. Microstructure of material.

in the form of bubbles along with the impurities in the molten metal. Next, the purity of the molten metal was improved by using a ceramic filter. A Y-block of the high purity molten metal was cast. This Y-block was then subjected to T6 heat treatment, which involved solution heat treatment and artificial aging.

The microstructures of the test piece are shown in Fig. 1. The AC4CH material comprises an α-Al phase dendritic structure and eutectic silicon particles. The average second dendrite arm spacing was about 29 μm. Fig. 2 shows the shape of the fatigue test specimens. The specimens have a circumferential shallow notch at their center that imparts a stress concentration factor K_t of about 1.04. After machining, the center part of the specimen was subjected to the LPwC treatment.

2.2. Laser peening without coating and fatigue testing

The center part of the fatigue specimen was laser peened without coating with a Q-switched and frequency-double Nd:YAG laser. The LPwC treatment was performed under the conditions of 100 mJ pulse energy, 0.6 mm Ø spot diameter, 27.3 pulses/mm^2 irradiation density, and 770% coverage. The materials are referred to as the DG-LP materials.

Rotating bending fatigue tests at 2760 rpm were conducted in air at room temperature using two types of materials, i.e., degassing process AC4CH (DG) material and laser-peened DG (DG-LP) material. To investigate the effect of the LPwC treatment on the surface crack propagation behavior, the surface fatigue cracks were observed using a replication technique. The fracture surfaces were examined after the tests using scanning electron microscopy (SEM).

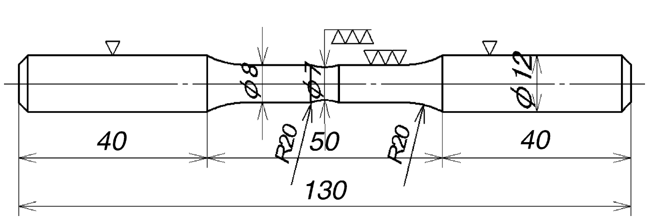
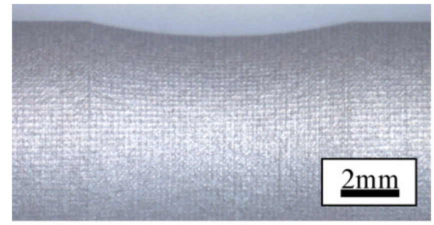


Fig. 2. Shape and dimensions of fatigue test specimens [mm].



	R_a [μm]	R_z [μm]
DG	0.1	0.7
DG-LP	3.6	22.0
DG-SP [7]	5.1	25.3

Fig. 3. Macro image of DG-LP specimen.

3. Experimental results and discussion

3.1. Surface roughness and hardness distribution

The surface roughness was measured. Fig. 3 shows a macro image of the DG-LP material surface and the surface roughness for each material. The surface roughness – R_a and R_z – clearly increased by the LPwC treatment. However, they were lower than that for the shot peened DG material (DG-SP) at mild shot peening conditions [7].

The hardness distribution of the laser peening affected layer near the surface of the specimen was measured using a micro-Vickers hardness tester at 0.098 N. Fig. 4 shows the relation between the Vickers hardness and the depth from the surface. The surface layer of the DG material hardened at about 20 Hv by machining when the specimen was formed. On the other hand, the hardness of the surface layer up to a depth of 400 μm from the surface for the DG-LP material was about 10 Hv higher than that of the DG material.

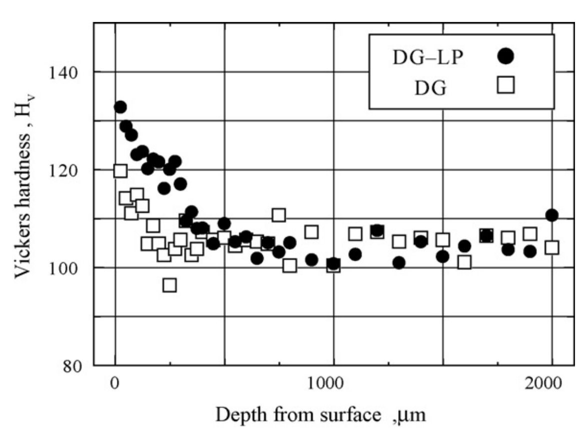


Fig. 4. Hardness distribution of DG-LP and DG specimens.