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Effect of shot peening using ultra-fine particles on fatigue properties of 5056 aluminum alloy under rotating bending

Shoichi Kikuchi [a],*, Yuki Nakamura [b], Koichiro Nambu [c], Masafumi Ando [d]

[a] Department of Mechanical Engineering, Graduate School of Engineering, Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe-shi, Hyogo 657-8501, Japan
[b] Department of Mechanical Engineering, National Institute of Technology, Toyota College, 2-1 Eisei-cho, Toyota-shi, Aichi 471-8525, Japan
[c] Department of Mechanical Engineering, National Institute of Technology, Suzuka College, Shiroko-cho, Suzuka-shi, Mie 510-0294, Japan
[d] Innovation Team, IKK SHOT Co. Ltd., 412-4, Nunowari, Minami-Shibata-machi, Tokai-shi, Aichi 476-0001, Japan

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ABSTRACT

Shot peening using particles 10 μm in diameter (ultra-fine particle peening: Ultra-FPP) was introduced to improve the fatigue properties of 5056 aluminum alloy. The surface microstructures of the Ultra-FPP treated specimens were characterized using a micro-Vickers hardness tester, scanning electron microscopy (SEM), X-ray diffraction (XRD), non-contact scanning white light interferometry, and electron backscatter diffraction (EBSD). The Ultra-FPP treated specimen had higher hardness than the conventional FPP treated specimen with a short nozzle distance due to the high velocity of the ultra-fine particles. Furthermore, the surface hardness of the Ultra-FPP treated specimen tended to increase as the peening time decreased. Fatigue tests were performed in air at room temperature using a cantilever-type rotating bending fatigue testing machine. It was found that the fatigue life of the Ultra-FPP treated specimen tended to increase with decreasing peening time. Mainly, the Ultra-FPP improved the fatigue properties of 5056 aluminum alloy in the very high cycle regime of more than 10^7 cycles compared with the un-peened specimens. This is because the release of the compressive residual stress is small during fatigue tests at low stress amplitudes.

1. Introduction

Recently, the reduction of greenhouse gas (GHG) production has become one of the most important subjects regarding efforts to combat global climate change. Since the use of light-metal alloys as structural parts of mechanical components is effective for weight saving, improving efficiency and decreasing GHG emissions, it would be beneficial to improve their fatigue strength because most machine and structural parts exhibit fatigue failure in the fields of engineering. Shot peening is one of the most common surface modification techniques for improving the fatigue properties of materials [1–14], due to the formation of a surface-hardened layer and the generation of compressive residual stress.

Fine particle peening (FPP) is more effective for improving the fatigue properties of materials than conventional shot peening [1]. FPP is very similar to the conventional shot peening method except that the shot particles used in FPP (less than 200 μm in diameter) are much smaller than those used in shot peening (e.g. 510 μm [15], 600 μm [3], 700 μm [10], 800 μm [1,16,17] and 4 mm [13] in diameter). In previous reports, the effects of the shot particle size on the microstructural changes and fatigue properties of materials were investigated [1,15,16,18]. Yonekura et al. [1] reported that the fatigue strength of FPP treated ferrite-pearlite steel was higher than that of the same material treated with conventional shot peening due to the generation of higher and more stable compressive residual stress on the treated surface. Moreover, FPP is very effective for creating fine crystal grains [15,16,18,19] because the particle velocity in FPP is higher than that in conventional shot peening [17,20,21].

Based on these reports, it is expected that the fatigue strength will be improved by performing shot peening using finer shot particles. In this study, ultra-fine particle peening (Ultra-FPP) using particles 10 μm in diameter was introduced to improve the fatigue properties of 5056 aluminum alloy. However, various peening conditions influence surface properties such as surface roughness, hardness and residual stress, which all affect fatigue properties [9–11]. Therefore, the effects of Ultra-FPP on the surface properties of the material should be examined to determine the condition that achieves the highest fatigue strength.

The purpose of this study is to examine the effects of Ultra-FPP

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* Corresponding author.
E-mail address: kikuchi@mech.kobe-u.ac.jp (S. Kikuchi).

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on the surface microstructure of 5056 aluminum alloy. Furthermore, the fatigue properties of 5056 aluminum alloy treated with Ultra-FPP in the very high cycle regime (around 10^9 cycles or giga-cycles) were experimentally investigated by performing fatigue tests under rotating bending.

2. Experimental procedures

2.1. Material and specimen preparation

5056 aluminum alloy with the certificated chemical composition shown in Table 1 was used in this work. The certificated mechanical properties of this material are shown in Table 2. Fig. 1 shows a cross-sectional optical micrograph of this alloy with a 78 µm average grain size.

Material rods 12 mm in diameter were machined into 5 mm thick disks for analyzing the surface microstructure and into hourglass-type specimens for fatigue tests and residual stress measurement. Fig. 2 shows the configuration of the hourglass-type specimen. The diameter of the critical portion with a round notch at the center is 4.5 mm. After machining, these specimens were annealed at 473 K for 2 h.

Ultra-FPP was performed for the disk and hourglass-type specimens under the conditions given in Table 3. In this study, we changed the particle diameter, nozzle distance, peening pressure, and peening times. Fig. 3(a) shows a scanning electron microscopy (SEM) micrograph of the 10 µm diameter shot particles, which had a Vickers hardness of 862 HV and the chemical composition, which was measured by the of authors, shown in Table 4. For comparison, 50 µm diameter shot particles used for conventional FPP were also prepared, as shown in Fig. 3(b).

2.2. Characterization of the surface-modified layer

The hardness distributions were measured along the longitudinal section of the disk specimen using a micro-Vickers hardness tester at a load of 0.098 N. The surface microstructure of the specimens was characterized using SEM, non-contact scanning white light interferometry, and electron backscatter diffraction (EBSD). The residual stress was also measured for the transverse section of the smallest diameter of the hourglass-type specimen by X-ray diffraction (XRD) using CrKα radiation with a position-sensitive proportional counter (PSPC) system based on the $\sin^2\psi$ method [22,23]. The conditions for measuring the residual stress are shown in Table 5.

2.3. Fatigue tests

Fatigue tests were performed using a dual-spindle rotating bending fatigue testing machine. This fatigue testing machine has two spindles driven by an electric motor via a V-belt, and each spindle has specimen grips at both ends. This machine can simultaneously perform fatigue tests on four specimens under rotating bending. The eccentricity of the specimens mounted to the specimen grips was kept within 20 µm at the tip of the specimen. This type of testing machine was originally developed to perform a

Table 1
Chemical composition of 5056 aluminum alloy (mass%).

Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
0.04	0.13	0.01	0.06	4.8	0.06	0.02	Bal.

Table 2
Mechanical properties of 5056 aluminum alloy.

Tensile strength (MPa)	0.2% proof stress (MPa)	Elongation (%)	Vickers hardness (HV)
310	218	21	88

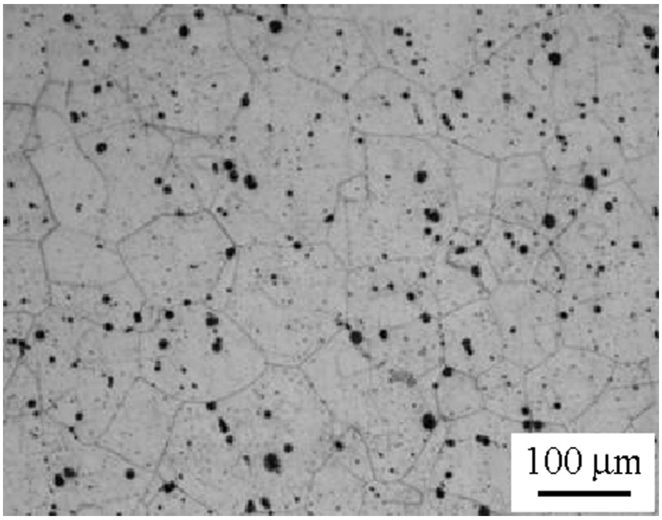

Fig. 1. Cross-sectional optical micrograph of 5056 aluminum alloy.

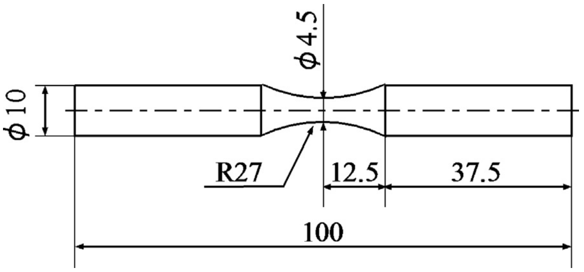

Fig. 2. Specimen configuration for fatigue tests and residual stress measurement.

Table 3
Peening conditions for (a) disk specimen and (b) hourglass-type specimen.

(a) Series	Particle diameter (µm)	Nozzle distance (mm)	Peening pressure (MPa)	Peening time (s)
Ultra-FPP	10	30	0.6	3
				10
				30
		50	0.2	3
			0.4	
			0.6	
FPP	50	50	0.2	3
			0.4	
			0.6	
(b)				
Ultra-FPP	10	30	0.6	5
				10
				30
		50	0.2	10
			0.4	
			0.6	
FPP	50	50	0.6	10