INFLUENCE OF PEENING ON FATIGUE LIFE OF SiC REINFORCED ALUMINUM

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ABSTRACT

There is an ever increasing need for better automotive fuel economy and improved engine performance. To meet this worldwide need, one of the most effective means is to reduce the weight of engine parts. To achieve this, metal matrix composites (MMCs) are widely considered over conventional materials such as aluminum or magnesium. This is due to the outstanding rigidity and strength properties of MMCs at high temperatures.

This paper describes the process of shot peening aluminum composites which are reinforced with silicon carbide whisker (SiCw) or silicon carbide particle (SiCp). It further investigates the influence of shot peening on fatigue life by means of residual stress and MMC structure (distribution of whisker).

As a result, after shot peening the fatigue strength of SiCp/2024 was improved but there was little effect on the SiCw/6061. The reason for this was found to be that, shot peening affected the surface's residual stress.

KEYWORDS

Aluminum, MMC, SiC, Shot peening, Fatigue life, Residual stress, Surface roughness

INTRODUCTION

Using Metal Matrix Composite (MMC) for engine parts is considered to be very effective in reducing weight, fuel consumption and direct operating cost. Whisker and particle reinforced MMC are expected to have improved fatigue strength over that of matrix aluminum alloy. The shot peening process was investigated in an effort to further increase this expected benefit.

This paper describes the use of the shot peening process on aluminum composite (MMC) reinforced with silicon carbide whisker (SiCw) or silicon carbide particles (SiCp). It further describes the investigation of the influence of shot peening on fatigue life by considering the residual stress and the distribution of whisker and particles in the composite.

EXPERIMENTAL PROCEDURE

Table 1 describes the MMC materials used in testing. One material consists of an A6061 metal matrix with a 20 % volume fraction of SiC whisker, made by squeeze casting. The other is an A2024 metal matrix reinforced with a 20 % volume fraction of SiC particles, produced by powder metallurgy. These MMCs were then machined to 70 mmϕ x 10 mm or 90 mmϕ x 20 mm, heat treated as shown in Fig. 1, and then machined as shown in Fig. 2.

Table 1 MMC materials used in testing

Specimen	SiC	SiC Vf	Matrix	Production Method
SiCw/6061	Whisker	20%	6061	Squeeze Casting
SiCp/2024	Particle	20%	2024	Powder Metallurgy

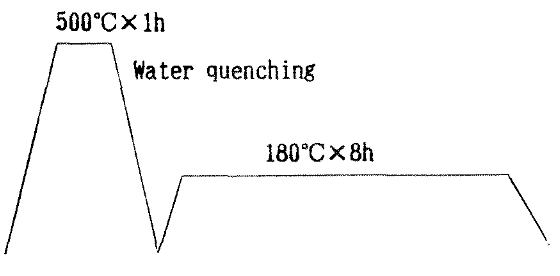


Fig. 1 Heat treatment condition

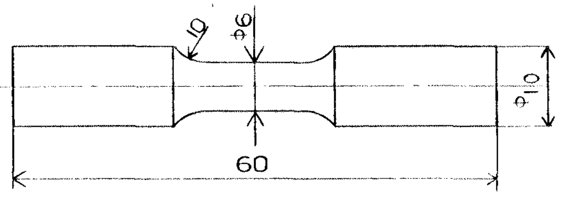
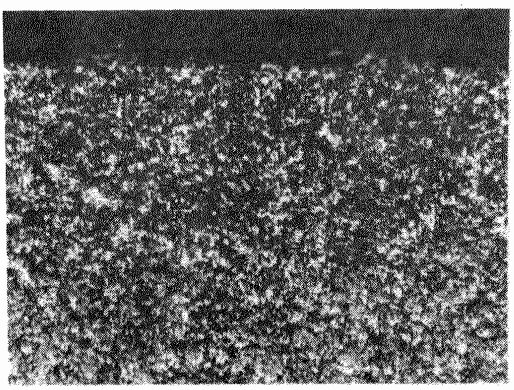


Fig. 2 Sample dimensions

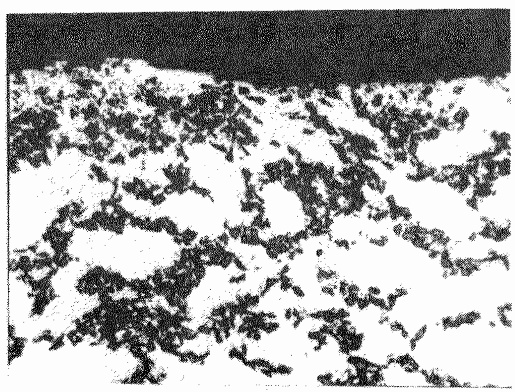
Table 2 shows the mechanical properties of the test samples and Fig. 3 displays their optical photomicrographs. As shown in Table 2, the MMCs' hardness and Young's modulus are greatly improved over those of matrix aluminum. Tensile strength of SiCw/6061 which is reinforced with SiC whisker is improved about 100 % compared with matrix aluminum, but tensile strength of SiCp/2024 which is reinforced with SiC particles is equal to that of matrix aluminum. Fig. 3 shows that there is a large difference in the distribution of SiC between SiCw/6061 and SiCp/2024. That for SiCw/6061 is equal, whereas that for SiCp/2024 is reticulated. The shot peened surface displays some convex and some concave areas indicating increased density of SiC.

Table 2 Mechanical properties of test piece

Material	Hardness	Tensile strength	Young's modulus
SiCw/6061	Hv 150	550 MPa	110 GPa
SiCp/2024	Hv 170	500 MPa	100 GPa
6061	Hv 90	280 MPa	70 GPa
2024	Hv 135	500 MPa	70 GPa



a) SiCw/6061

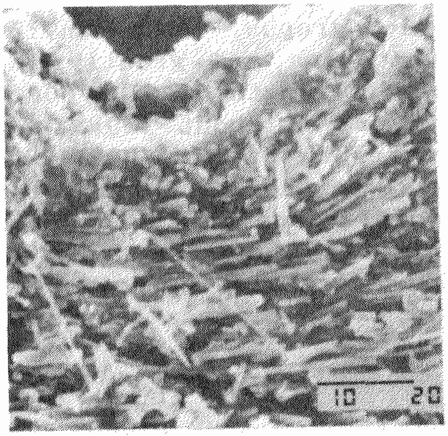


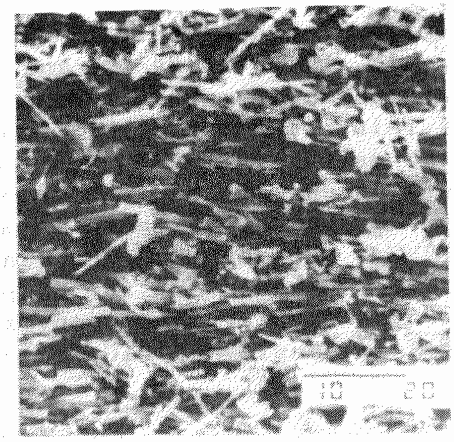
b) SiCp/2024

Fig. 3 Optical photomicrographs

In Fig. 4 the distribution of SiC whisker in the SiCw/6061 sample is evident in the SEM photomicrograph. At the surface the whisker concentration is higher and the whiskers are parallel to the surface.

The shot peening process has the sample secured to a turn table revolving at a speed of 20 rpm as shown in Fig. 5. Glass beads are projected at the sample through a 5 mm diameter nozzle at 0.3 MPa at a right angle to and 150 mm from the center of the sample.





a) near surface b) inner part

Fig. 4 SEM photographs of fracture surface of SiCw/6061

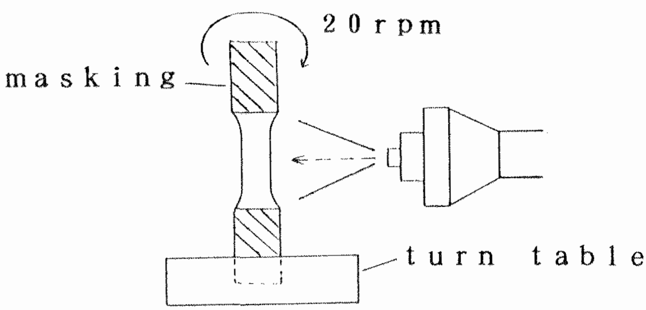


Fig. 5 Schematic peening apparatus

Table 3 shows surface treatment conditions.

The hardness distribution of the MMC samples after shot peening is shown in Fig. 6. The hardness was 30 to 40 points higher at the surface than inside. This confirms that shot peening is effective in increasing surface hardness for MMC just as it is for steel and aluminum [1]-[3]. Fig. 7 shows correlation between shot peening conditions and matrix aluminum, relative to surface roughness. For both materials, as arc height increases the surface roughness also increases, showing that shot peening creates plastic deformation. Fig. 8 shows surface properties of SiCw/6061 test piece after shot peening.

Table 3 Surface treatment conditions

arc height (N)	coverage	shot dia.	time
0.32 mm	300 %	250-177 μm	15 sec
0.20 mm	300 %	125-105 μm	15 sec

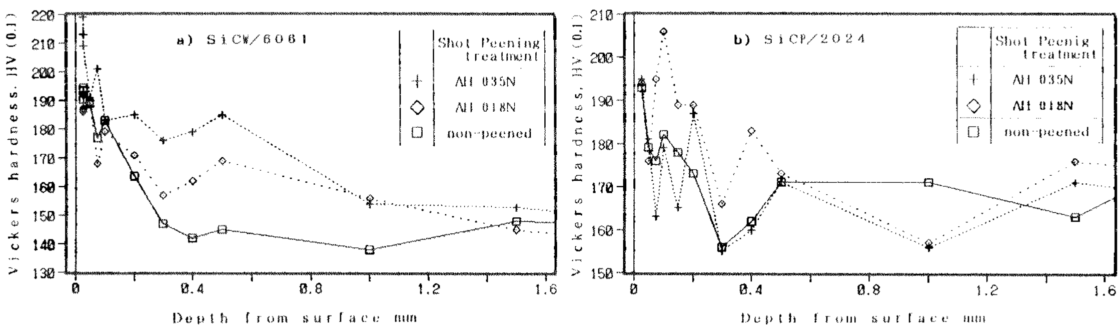


Fig. 6 Hardness distribution of MMC sample after shot peening

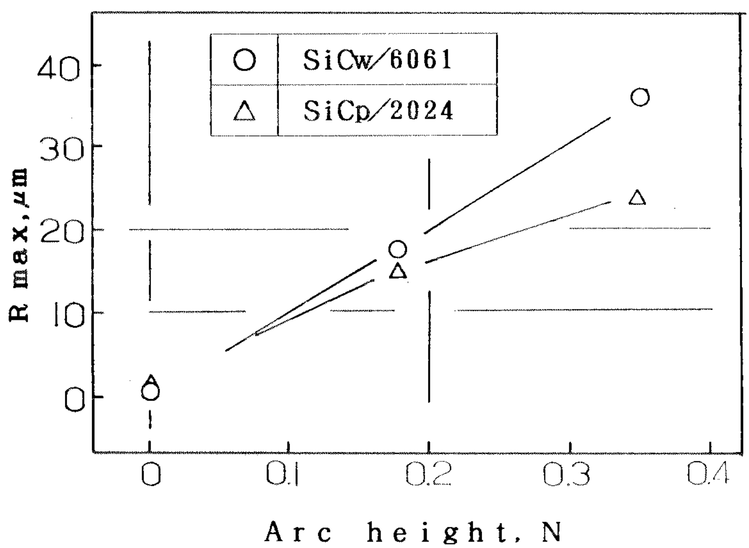


Fig. 7 Correlation between shot peening conditions and matrix aluminum, relative to surface roughness

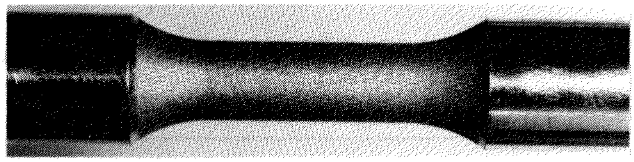


Fig. 8 Surface properties of MMC after shot peening (SiCw/6061)

RESULTS AND DISCUSSION

1. Results of Rotating Bending Fatigue Tests

SiCw/6061 and SiCp/2024 materials were shot peened under 2 different conditions, and rotating bending fatigue tests were conducted. The results are shown in Fig. 9. Reinforcement with SiC particles can increase the fatigue limit by 60 % compared with A2024 aluminum, and reinforcement with SiC whisker can increase the fatigue limit by 100% compared with A6061 aluminum. Besides that, further shot peening improves the low cycle side fatigue strength of SiCp/2024, but the high cycle side fatigue strength was lowered to be approx. 10 MPa. There was no difference in fatigue strength by difference of shot peening conditions. Fatigue strength of SiCw/6061 was not improved by shot peening.

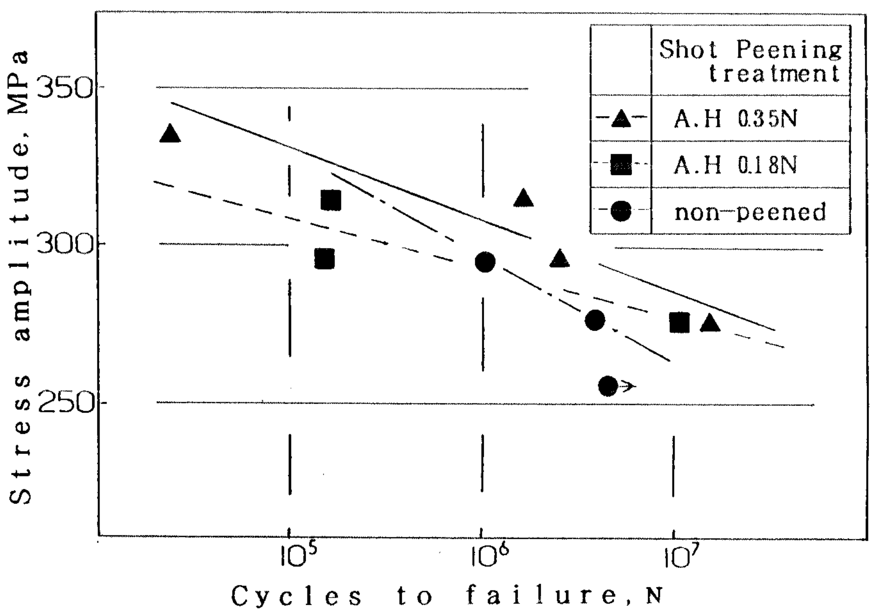


Fig. 9 a) S-N curves (SiCw/6061)

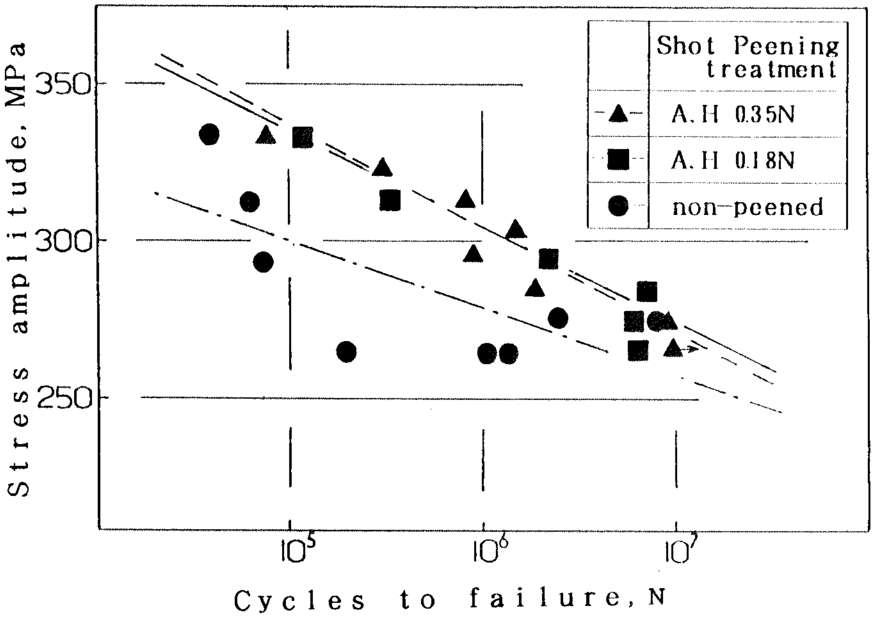
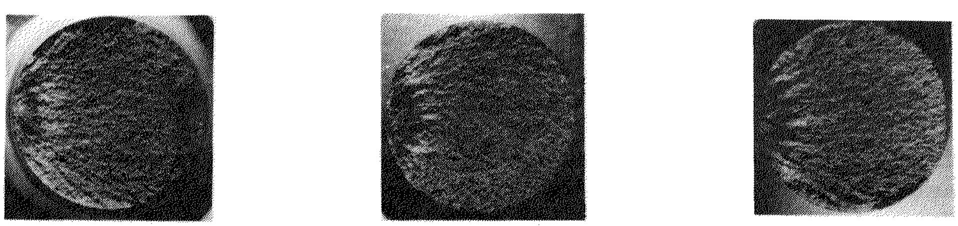


Fig. 9 b) S-N curves (SiCp/2024)

The fractography of the samples is shown in Fig. 10. Fracture originates from the surface in all cases and arc-shaped white area, called "fish-eye", was observed at the origin of fracture. There is no difference in fracture surface morphology, irrespective of shot peening, SiC characteristics, or number of cycles to failure.



a) non-peened b) A.H 0.35N c) A.H 0.18N

Fig. 10 Fracture surface of specimens (SiCp/2024)

2. Influence of Surface Residual Stress on Fatigue Strength of MMCs

Residual stress on the sample's surface was measured in order to determine the effect of shot peening on fatigue strength. Fig. 11 shows the X-ray diffraction pattern of MMC. As a result, Al(222) peak around 100° was confirmed and residual stress was measured under the conditions shown in Table 4.

Table 4 Measuring conditions of residual stress

characteristic of X-ray	Cr-Kα
diffraction plane	[222]
voltage	30 kV
current	10 mA
filter	V foil
irradiated area	3 x 4 mm^2

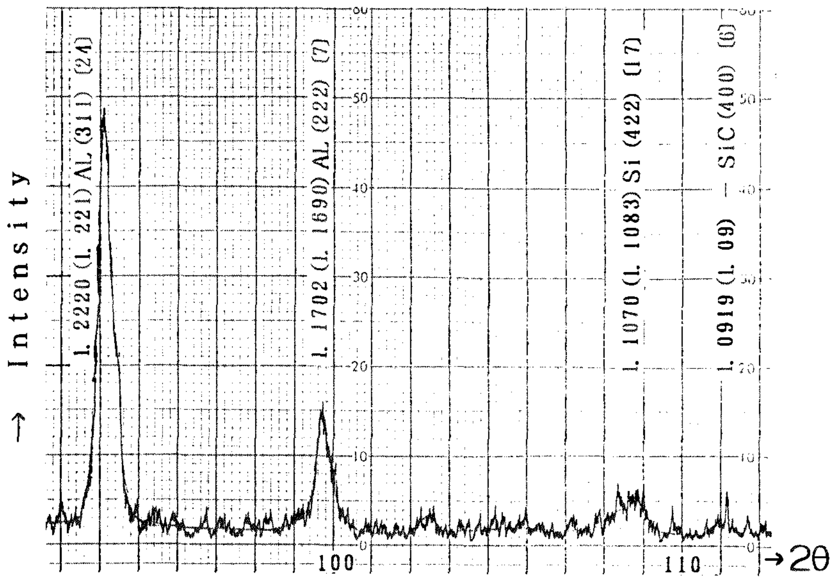


Fig. 11 X-ray diffraction pattern of MMC

Before taking measurements, the actual residual stress and the measured value were calibrated. Initially, a sample plate was made and strain gauges were affixed as shown in Fig. 12. Values of strain and measurement were calibrated when bending moment was applied to the sample.
Fig. 13 shows correlation between measured strain by means of X-ray diffraction and actual value by strain gauge. As inclination rate is 0.96 (nearly equal to one) and correlation coefficient is 0.808, it was determined that taking measurement of Al(222) peak was effective in order to know MMC's residual stress.

Fig. 14 shows correlation between surface residual stress obtained by X-ray diffraction, and the fatigue life at 300 MPa stress amplitude. It clearly shows that improvement of fatigue strength of MMC by shot peening is in negative correlation with surface residual stress for both SiCw/6061 and SiCp/2024.

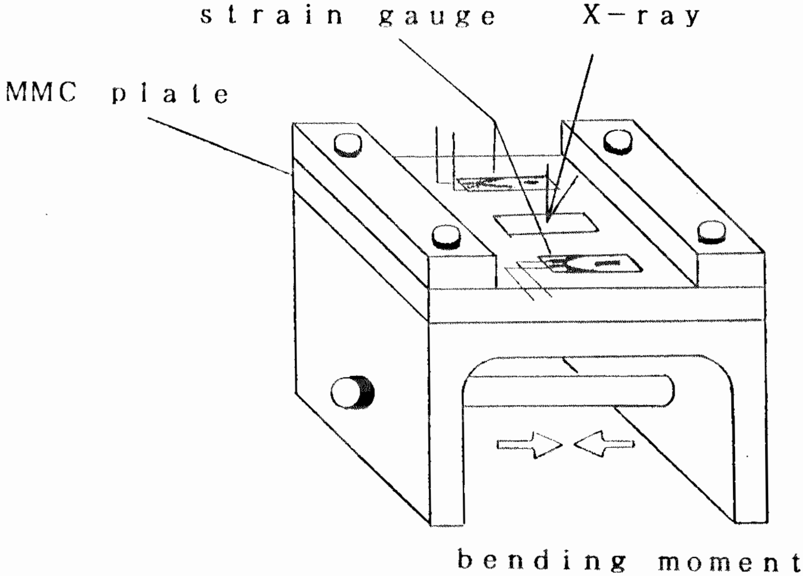


Fig. 12 Schematic calibration apparatus

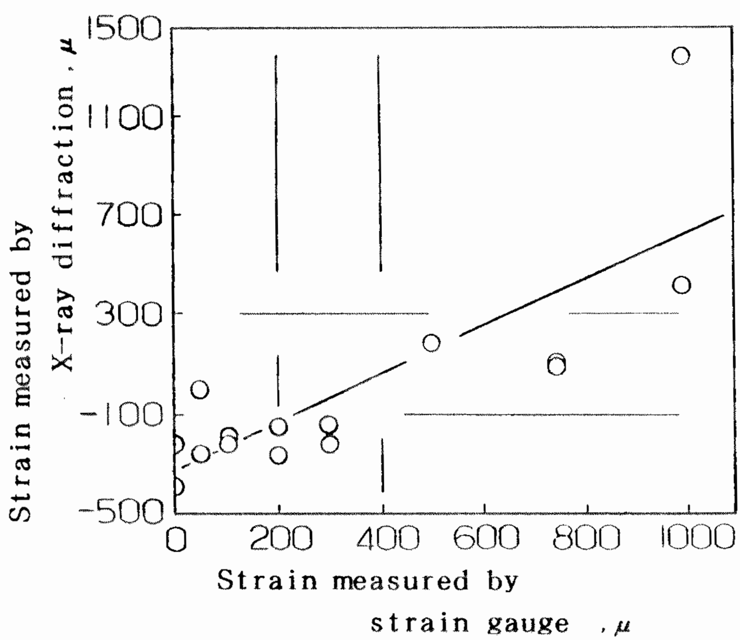


Fig. 13 Correlation between the strain measured by X-ray diffraction and the actual value by strain gauge

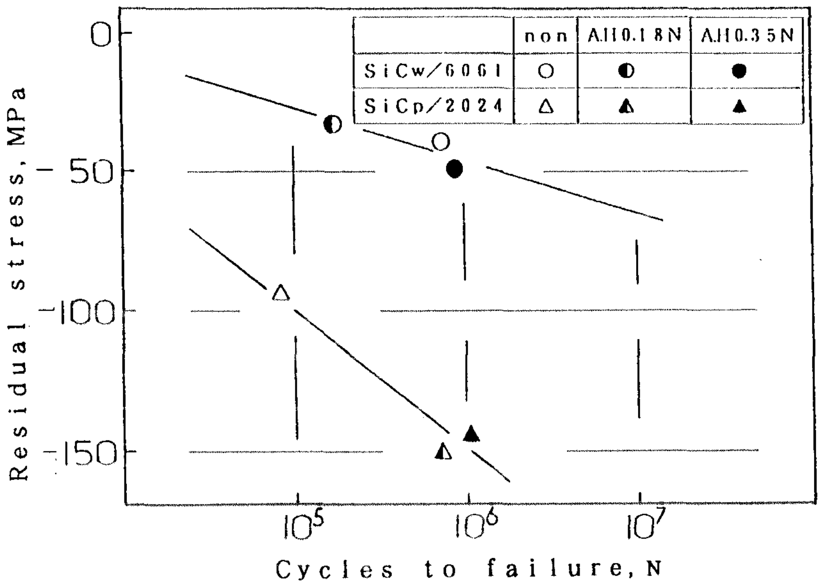


Fig. 14 Correlation between surface residual stress and fatigue life at 300 MPa stress amplitude

CONCLUSION

By investigating the influence of shot peening upon the fatigue strength of SiCw/6061 and SiCp/2024, the following conclusions can be drawn:

1. Shot peening improves the fatigue strength of SiCp/2024.

2. The fatigue strength of SiCw/6061 is not affected by shot peening.

3. Residual stress influences the above conclusions when measured by X-ray diffraction on the specimen surface. Engineering efforts should be further directed to determine why residual stress of SiCw/6061 was not increased by shot peening.

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