

EFFECT OF SHOT PEENING ON FATIGUE PERFORMANCE OF ADVANCED ALUMINIUM ALLOYS AND ALUMINIUM BASED METAL MATRIX COMPOSITES

Hill S., Gregson P.J. and O'Hara P.*

*Engineering Materials, University of Southampton, UK

**Metal Improvement Company, UK

ABSTRACT

Future airframe designs may incorporate the lightweight lithium-containing aluminium alloys and silicon carbide reinforced aluminium alloys which offer enhanced specific stiffness and strength. The present research set out to investigate the influence of shot peening on the fatigue performance of the monolithic and composite materials under rotating bend loading conditions with a stress ratio $R = -1$. The metal matrix composites are shown to respond favourably to shot peening for a given set of parameters, but severe peening may lead to excessive surface roughness.

KEYWORDS

Fatigue, Al-alloy, Metal Matrix Composites

INTRODUCTION

For the development of future lightweight structurally efficiency aerospace components, three categories of structure emerge, namely those that are critical in terms of strength, stiffness, and tolerance to fatigue damage. High levels of specific stiffness are afforded by the lithium-containing aluminium alloys, and these are now specified for application on both military and civil aircraft. The combination of an aluminium alloy with reinforcement by particulate silicon carbide (SiC) to produce an isotropic metal matrix composite (MMC) offers the possibility of much enhanced specific stiffness together with improved strength (1). For all aerospace materials mechanical, chemical and electrochemical surface treatments (eg shot peening, pickling, anodising) may be incorporated to improve service performance. Of these shot peening may be undertaken to enhance component properties, form or rectify shape of aluminium and titanium alloy wing or fuselage components produced by conventional machine cutting, chemical machining or creep/age forming. The near-surface compressive residual stresses serve to improve the fatigue life of treated components (2), reduce their susceptibility to stress corrosion cracking (3) and improve fretting and fretting fatigue resistance (4). The present work set out to investigate the effect of a commercial shot peening process on the fatigue performance of monolithic Al-Li based alloys and Al-based MMCs incorporating particulate SiC.

EXPERIMENTAL PROCEDURE

Nominal compositions for the alloys and MMCs under investigation are given in Table 1; all materials were supplied by Alcan International. Monolithic materials had been DC cast and rolled to 65mm plate prior to heat-treatment; MMCs were spray formed and subsequently extruded to 65 x 25mm section. All materials were heat-treated to a notional T6 temper: 8090 and 8090MMC were age-hardened for 48h at 170C while 2618MMC was treated for 16h at 190C. Monotonic mechanical properties (T/L orientation) were determined using tensile test-pieces having a 25mm gauge length and 3.85mm section diameter with the testing conditions conforming to BSA4.

Table I - Material Compositions

Material	Alloy / Reinforcement Content (wt%)						
	Li	Mg	Cu	Ni	Zr	Fe & Si	SiC (10 μ m)
8090	2.4	0.6	1.2	-	0.1	0.1	-
8090 MMC	2.3	0.6	1.2	-	0.1	0.1	10
2618 MMC	-	1.5	2.3	1.1	-	1.3	10

Waisted fatigue test-pieces of 4.06mm section diameter were taken in the T/L orientation and loaded in rotating bend at a load ratio $R=-1$ at a frequency of 66Hz. The test-pieces, together with flat specimens for surface characterisation, were polished and shot peened with 300 μ m steel shot to Almen 0.15 - 0.2mm A and decontaminated with 100 μ m glass beads to an Almen intensity of 0.1 - 0.15mm N. Past practices of shot peening with glass beads and low intensities do not impart the deep layers of compressive residual stresses required to meet today's need for damage tolerant surfaces. The present processing parameters were selected to represent preferred commercial practice for peening of monolithic Al-alloys: Initial processing with steel shot gives a deep layer of cold work in relation to section thickness and subsequent glass bead peening gives improved surface finish and removes ferrous stain.

The surface roughness was quantified by Talysurf measurement. Metallographic sections were polished and etched in Kellers reagent, whilst MMCs were anodised in Barkers solution and viewed under polarised light; image analysis was undertaken using a Kontron system. Scanning Electron Microscopy was carried out on a JEOL T300 SEM fitted with backscattered electron imaging (BEI) and energy dispersive x-ray microanalysis (EDX).

RESULTS

The grain structure, SiC reinforcement distribution and intermetallic precipitates within 2618 MMC are shown in Figure 1; additionally all materials contain various strengthening precipitates, but the intermetallic particles observed in 2618MMC are absent in the 8090-based materials. The grain structure and SiC reinforcement distribution are summarised in Table II. The monotonic properties of the heat-treated

alloys and MMCs are presented in Table III. Following shot peening the surface roughness of the test pieces was $Ra \sim 2.9\mu\text{m}$ for monolithic 8090 and in the range $Ra \sim 1.8\text{-}2.0\mu\text{m}$ for 2618MMC and 8090MMC.

Table II - Material Microstructure

Material	Grain Size T-ST Plane (μm)	Average SiC Particle Size (μm)	Average SiC Area Fraction (%)
8090	25 x 100	-	-
8090 MMC	9	8.4	10.0
2618 MMC	35	9.7	9.2

Table III - Monotonic Mechanical Properties

Material	EI. Mod. (GPa)	0.2% P.S. (MPa)	U.T.S. (MPa)	% El. (%)
8090	78	389	498	8.0
8090 MMC	96	435	483	1.6
2618 MMC	95	441	507	1.6

Residual stress profiles computed from analytical models and incorporating practical peening parameters have been derived for the current processing conditions. Those for monolithic 8090 and 8090MMC are presented in Figure 2; the two MMCs will exhibit very similar stress distributions.

The fatigue life data for monolithic and reinforced 8090 is plotted as S-N curves in Figure 3. The fatigue limits, normalised with respect to material strength (UTS), were are summarised in Table IV.

Table IV - Fatigue Limits

Material	Polished	Polished & Shot Peened
8090	0.36	0.40
8090 MMC	0.33	0.40

DISCUSSION

The variation in grain structure between the materials reflects processing route and alloy composition. Rapid solidification via the spray-forming route refines the structure, and the very small grain sizes associated with the monolithic and reinforced 8090 reflects the extremely efficient grain refining influence of Zr in these Li-containing materials. Precipitation reactions occurring during heat-treatment are very different for

the two base materials, and are known to be influenced strongly by the presence of the SiC particles (5), but such changes per se are believed to be of little importance to the present work. Nevertheless their influence on the monotonic properties and on the deformation characteristics of the alloy matrix may be of significance. The mean SiC particle size in the MMCs was consistent, the variation in particle size and distribution being typical for the spray-forming MMC production process.

For the monolithic Li-containing alloy, shot peening showed a modest improvement in fatigue limit, in agreement with previous research using the same loading configuration (6). It must be remembered that the overall fatigue life will reflect the effect of shot peening on the initiation of fatigue cracks for which the increased surface roughness is detrimental, and their subsequent propagation for which the residual compressive stresses in the near surface layers are beneficial; hence modern practice of shot peening initially with greater depth in mind and finishing with lower intensities to reduce surface roughness.

The overall balance between initiation and fatigue crack growth will depend critically upon the loading conditions, and thus wide ranging comparisons are restricted and must be made with caution. For example the lower fatigue limit of reinforced 8090 than that of the monolithic alloy observed in the present work for loading in reverse plane bend is in apparent contradiction to previous results using tension/tension loading at $R=0.1$ (1) where the material strength accrues greater significance. Nevertheless comparison between the materials of the present research show some interesting trends with shot peening.

The fatigue limit of 8090 was increased by approximately 15%, consistent with previous research (5). Shot peening of MMCs resulted in a greater improvement ($\sim 30\%$) and restored the normalised fatigue limit to that of the shot peened monolithic material. The MMCs are stronger and have a higher elastic modulus than the unreinforced alloys, and their high strength is responsible for the increased residual peak stress and marginally reduced depth of compressive stress as evidenced from the stress profiles. The present loading geometry is such as to maximise the influence of local stress on initiation and very early stages of crack growth, hence promoting the improved performance of shot peened MMCs.

There was some evidence of SiC particle cracking in the surface layers of the MMCs during shot peening but further work is required to ascertain the influence of peening parameters and surface microstructure on the deformation and structural changes occurring during shot peening of MMCs. In the present work surface roughness after shot peening of the monolithic and reinforced materials was similar; however more severe peening (8600 μm steel shot to Almen 0.25mm A) caused increased surface roughness of MMCs reflecting heterogeneity of the substrate structure, and such irregularity might influence strongly the initiation of fatigue cracks and shot peened MMCs.

CONCLUSIONS

MMCs respond to shot peening and the present research has demonstrated an

improved fatigue performance for a particular set of parameters; this effect has been interpreted in terms of the residual stresses imparted to the substrate. Further work is required to optimise peening parameters to the substrate structure for MMCs. Severe peening (eg peen forming) of the MMCs should be approached with caution.

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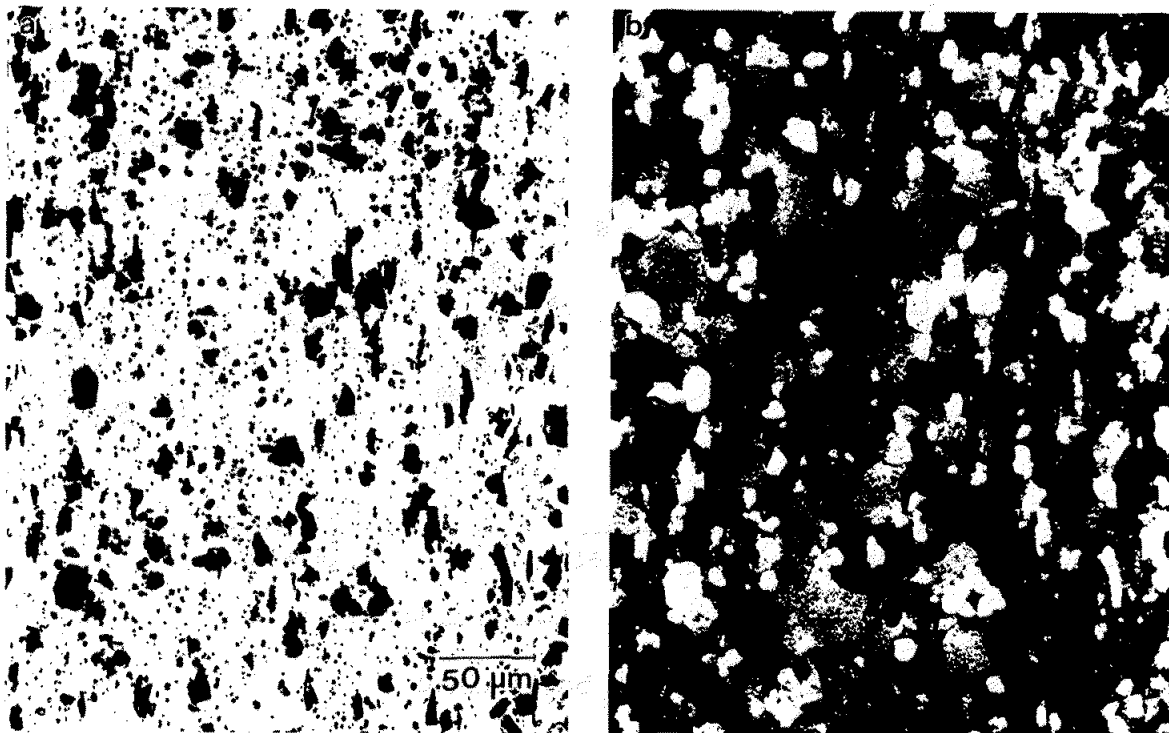


Figure 1 - Microstructure of 2618MMC viewed under (a) unpolarised and (b) polarised light showing SiC distribution and grain structure

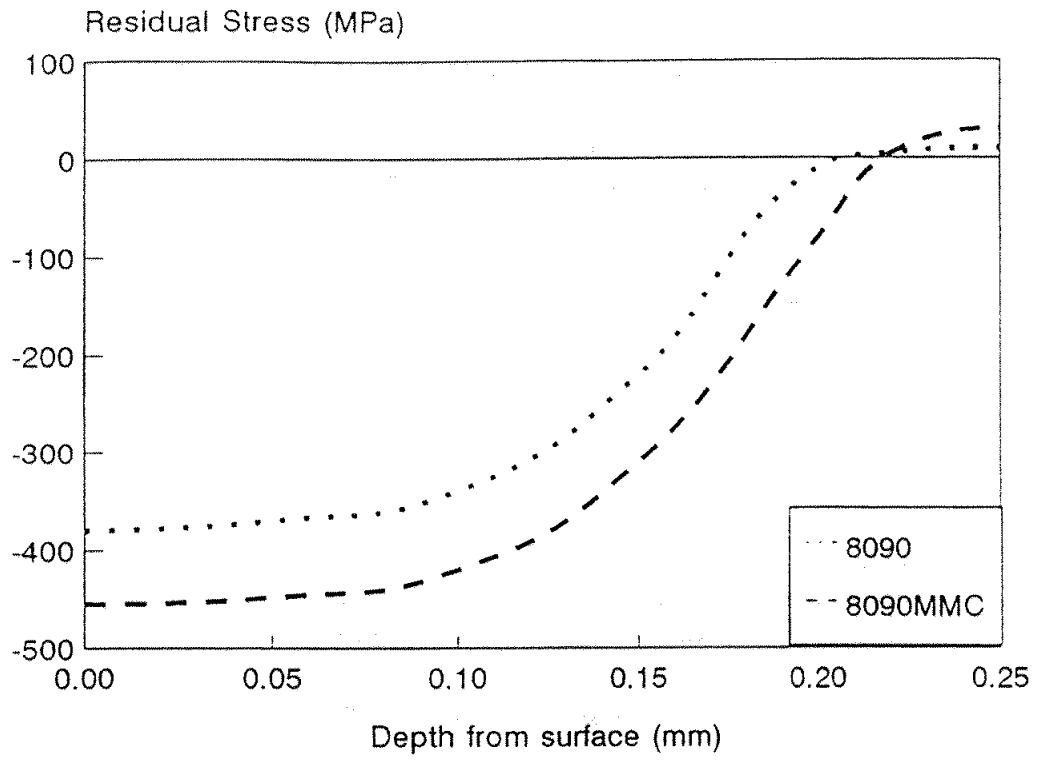
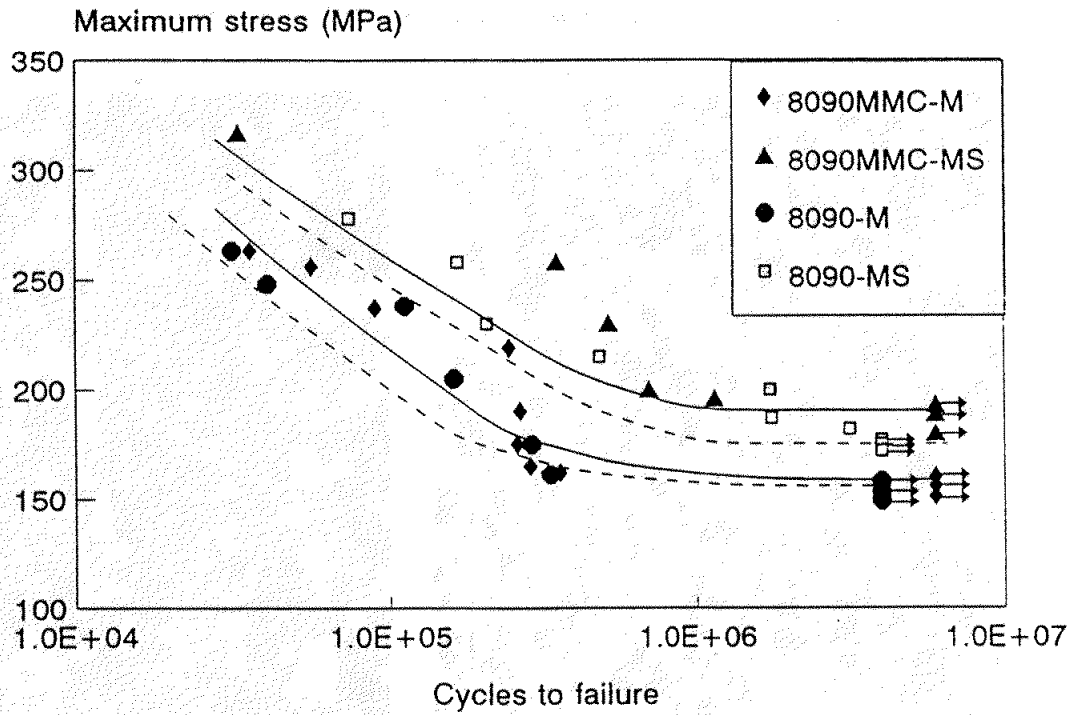


Figure 2 - Residual stress distribution after shot peening of 8090 and 8090MMC



M - Machined ; MS - Machined & Shot Peened

Figure 3 - Fatigue life of 8090 and 8090MMC having polished and shot peened surfaces