SIF2004 Structural Integrity and Fracture. http://eprint.uq.edu.au/archive/00000836

# The Effectiveness Of Repairing Fatigue Damaged 7050 Aluminium Alloy Using Shot Peening

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ABSTRACT Shot peening is an effective life extension surface treatment process. In this study, experiments were performed to investigate whether shot peening could be used to recover the fatigue resistance of aluminium alloy 7050 that has experienced prior fatigue damage. The results showed that shot peening may be used for restoring the original fatigue life of the material, but the effectiveness strongly depends on the amount of prior damage (*e.g.* the crack depth of any cracks that have already formed) in the material. A numerical model was established and the effect of residual stress was incorporated into the model. The prediction by the model agreed well with the experimental results in terms of trend.

## 1 INTRODUCTION

It is well recognized that surface modification technologies provide a means for enhancing the fatigue life of engineering components. For a component partially damaged in service, due to cracking, corrosion, or other mechanical causes, there is a strong incentive to attempt to restore its strength and durability through repair and rework and return it to service, provided that this can be done reliably and economically. Shot peening is one such surface treatment process for fatigue life enhancement. Shot peening involves impacting the surface with a flow of spherical shot or beads with carefully controlled kinetic energy, so that an appropriate amount of plastic strain is introduced on the surface of the material. Due to the elastic constraint of the deformed layer produced, a compressive residual stress field is produced on the surface of the component, which significantly slows or retards crack growth from the surface. It has been observed that the effectiveness of this surface treatment strongly depends on the amount of prior damage (*e.g.* the crack depth of any cracks that have already formed), the thickness of the peened layer (i.e. depth of the compressive residual stress layer), the material properties, and the quality of peening process.
This paper details the investigation into the effectiveness of glass bead peening in repairing fatigue-damaged areas in a high strength aluminium alloy 7050.

## 2 MATERIAL AND EXPERIMENTAL PROCEDURE

### 2.1 Material, Specimen Geometry and Test Matrix

The material under investigation was a thick section plate (150 mm thick plate) of 7050-T7451 aluminium alloy, which is mainly composed of ~2.07Cu, 2.05Mg, 6.05Zn and bal. Al in wt.%. The yield stress of the tested material is about 470 MPa. The test specimen used was dog-bone shaped, as shown in Figure1. In this testing, the un-peened specimens were fatigued to a known proportion of the total fatigue life (based on the result from un-peened specimens) to introduce fatigue damage, and then peened on both surfaces of a specimen. Over twenty specimens were tested, and the un-peened condition was taken as the reference condition.

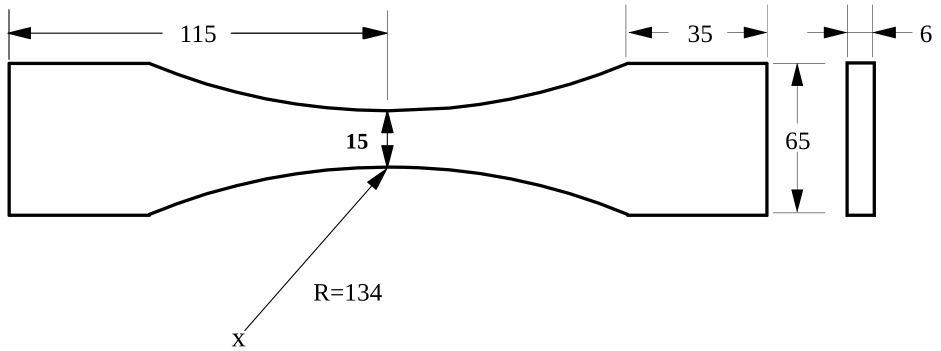



Fig.1 Schematic of geometry and dimension for a test Specimen

### 2.2 Fatigue Test Procedure

The fatigue tests were conducted on a MTS 100kN, digitally controlled test machine, under load control, using a fighter service wing root bending moment spectrum. The applied peak stress was 420 MPa. The test frequency was 10 Hz. Five specimens were tested for each percentage of un-peened fatigue life.

## 3 EXPERIMENTAL RESULTS AND DISCUSSION

The effect of prior fatigue damage (in percentage)[1] on repair effectiveness or fatigue life recovery (in percentage) by glass bead peening is shown in Figure 2, where the definition of the fatigue life recovery is as follows:

$$\text{Fatigue life recovery (in percentage)} = \frac{\textit{total life} - \textit{unpeened life}}{\textit{fully peened life} - \textit{unpeened life}} \times 100\%$$

The total life is defined as the number of prior fatigue damage programs in un-peened condition plus the programs to failure in peened condition.

From Figure 2, it is clear that if the prior fatigue damage is less than 50% of the un-peened life, there is a good chance to recover more than 60% of the original life[2], while if the prior damage is more than 80% of the un-peened life, recovery is almost nil. This appears to be related to the depth of the cracking prior to the peening operation. If the initial cracks are shallow, i.e. less than the depth of the peened layer (~ 250- 300 μm, refer to Figure 3), crack growth rate is retarded by the compressive residual stress, but if prior fatigue damage results in cracks deeper than the peened layer, the percentage of fatigue life recovery is significantly reduced. For example, at 60% of prior fatigue damage, only about 14% life improvement could be achieved for this material. This result also indicates that the highest fatigue life improvement is achieved during the early period of crack growth. For example, the number of programs of load spectrum needed to grow a crack to the first 250-300 μm (approximately the thickness of the peened layer) in the damaged specimens is about 8 to18, depending on the percentage of prior fatigue damage, compared to 22 programs of loading in the fully peened specimens (Figure 4). Additionally, there was no effect if the prior fatigue damage was over 80%, because the crack depth induced by the prior fatigue damage was more likely to have extended deeper than the depth of the compressive residual stresses provided by the peening process (typically ~250-300 μm in aluminium alloy) and the beneficial effect of compressive residual stress was significantly reduced.

[1] The prior fatigue damage in percentage is defined as a fraction of the life in un-peened condition.
[2] The original fatigue life means the life in fully peened condition without any prior fatigue damage.

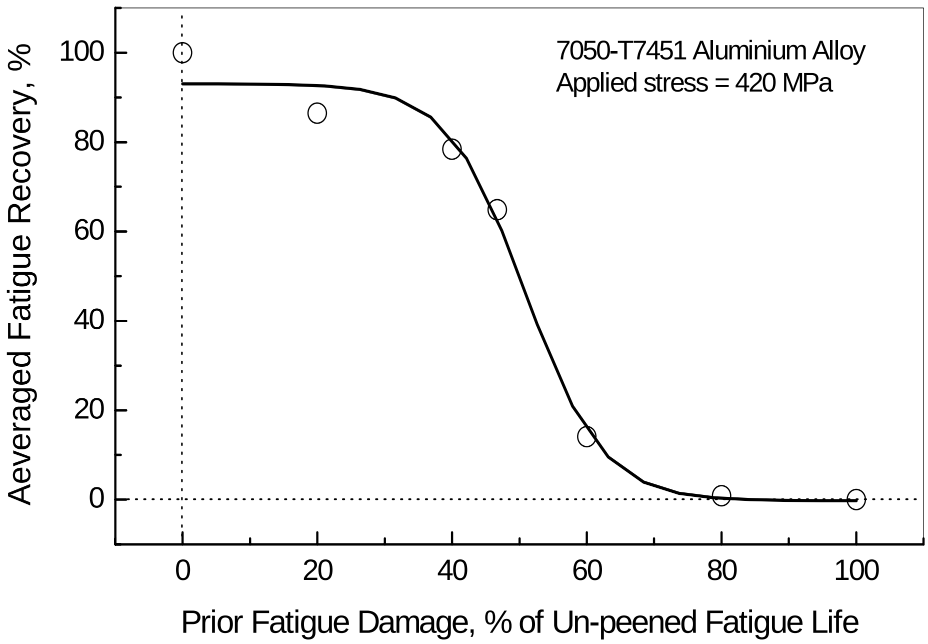



Fig.2 Average fatigue recovery as a function of prior fatigue damage by glass bead peening

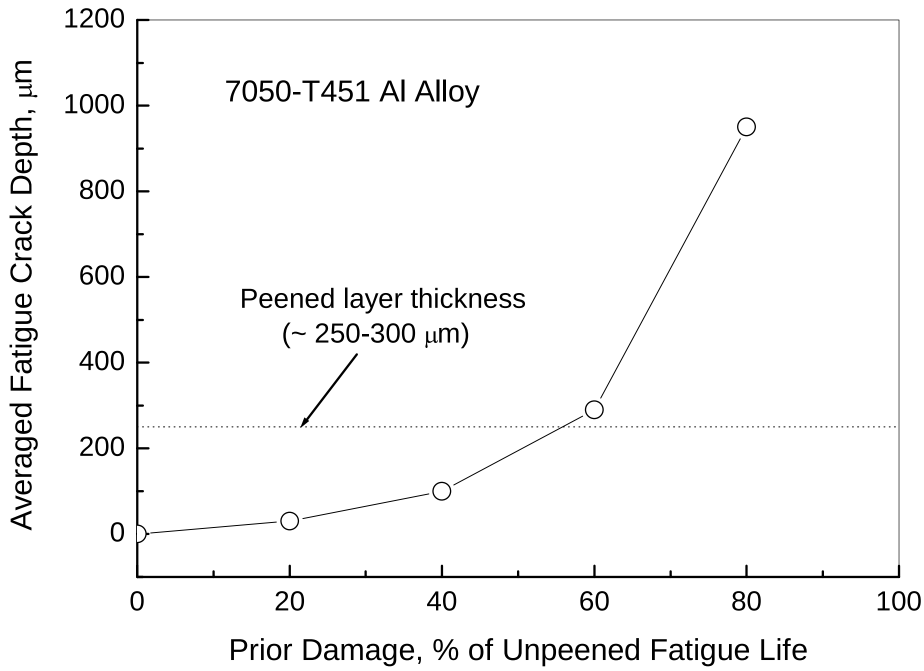



Fig.3 Relationship between the average fatigue crack length and the prior damage in percentage of un-peened fatigue life

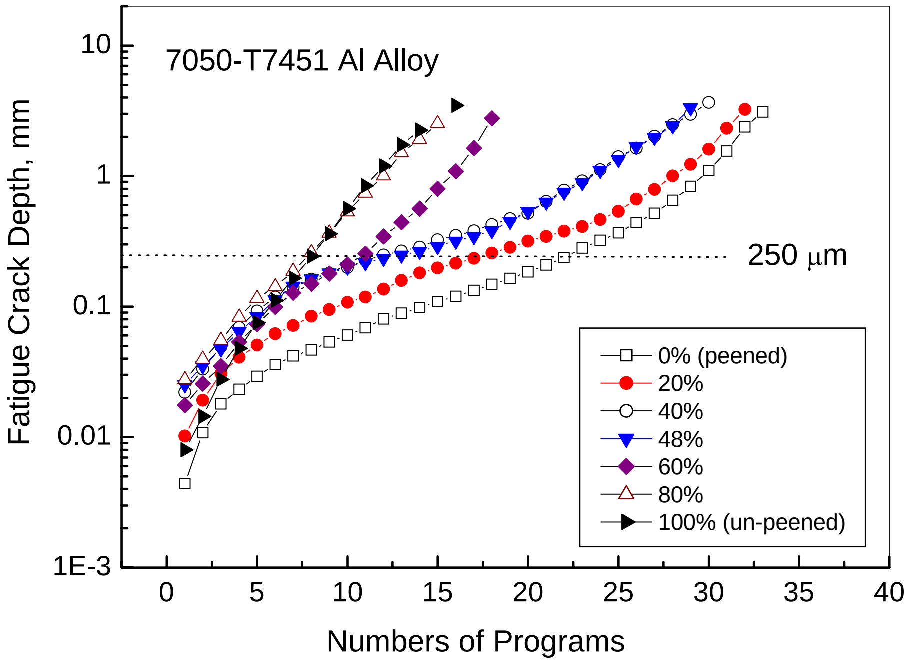



Fig.4 Crack growth curves after shot peening treatment for different percentages of prior damage

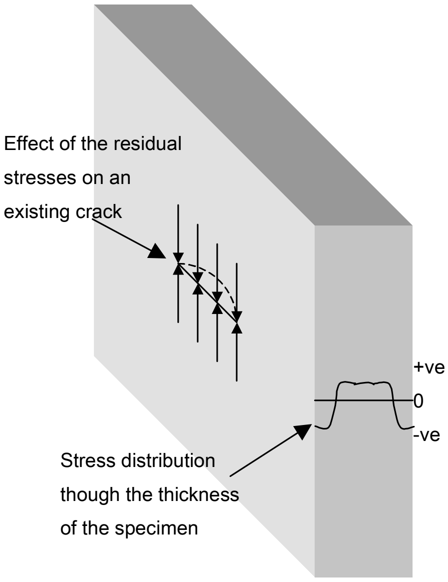
## 4 NUMERICAL ANALYSIS

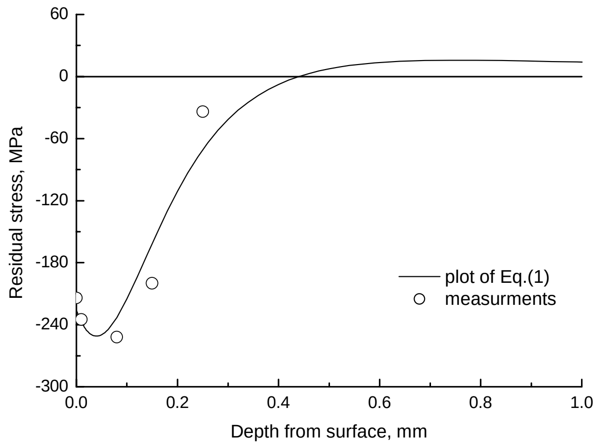
The effectiveness of shot-peening in extending fatigue life depends on the magnitude and distribution of the residual stress field, which in turn is influenced by a number of peening parameters, such as the hardness and size of the shot, the kinetic energy transferred by the shot to the surface of the material, the coverage and the tensile strength of the peened part. As shown schematically in Figure 5, the residual stress is uniformly distributed across the surface of the plate, but in the thickness direction, it has a large gradient. The compressive residual stress is maximum just below the surface and drops rapidly to zero, before it crosses over to a very small tensile residual stress. Therefore, the residual stress can be modelled as a function of depth only. The specific function and its parameters need to be determined from experimental results.

For the glass bead peening carried out in this investigation, the compressive residual stress distribution is illustrated in Figure 5, which can be fitted by the following equation. This is an improved model over that used in [Wang and Liu 2002],

$$\sigma_{RI} = a\sigma_{R\max} \frac{1-(z-z_0-d)^2}{\left[1+(z+z_0)^2/d^2\right]^2} \qquad (1)$$

where $\sigma_{RI}$ is the initial distribution of residual stress; $\sigma_{R\max}$ is the maximum value of the compressive residual stress; $z$ the depth below the surface, $d$ the depth of the compressive residual stress and $a$ and $z_0$ are curve-fitting parameters . As a first approximation, we take $\sigma_{R\max} = -250$ MPa, $a$=2.08 and $d = 0.26$. Figure 5 (b) shows the plot of Eq. (1) and some experimental results. Combined with the Green function formulations, the above equation was implemented into the short crack-closure model, based on Newman's FASTRAN II program [Newman, 1992]. The details can be seen in the authors' report [2004].




(a) Surface crack (b) Residual stress distribution

Fig. 5 (a) Schematic residual stress distribution in the surface layer due to shot peening and (b) Experimental measurements together with the residual stresses predicted using equation (1)

Figure 6 shows the comparison of the predicted fatigue life for specimens with the experimental results for different levels of prior fatigue damage. Although a noticeable difference exists between the predicted life and the experimental data, the general trend of the prediction is good. The accuracy of the prediction is affected by the general capability of FASTRAN II, the assumed values of initial crack length corresponding to a particular amount of damage, and the approximation made in the calculation of $K_R$. A comparison of crack growth curve provided by FASTRAN II (20% prior fatigue damage, or equivalent initial crack length=20 $\mu m$) is shown in Figure 7, together with the experimental data. Again, a good correlation between experimental and numerical prediction is evident, although the prediction is slightly lower.

## 5 CONCLUSIONS

A series of fatigue tests on prior fatigue damaged 7050 Al specimens were performed. The conclusions drawn from this investigation are as follows.

(1) The effectiveness of the shot peening process in extending the life of damaged 7050 Al specimens depends mainly on the degree of prior fatigue damage that exists when shot peening is applied.

(2) When the prior fatigue damage is less than about 50% of the un-peened fatigue life, shot peening can produce fatigue life extension in the specimens tested.

(3) When the prior fatigue damage is greater than 50%, the fatigue life improvement or recovery is significantly reduced. At about 60% of the un-peened fatigue life, only about 14% fatigue life improvement can be achieved, but if the prior damage is more than about 80%, there is almost no fatigue life improvement over that of an un-peened specimen.

(4) A numerical model (FASTRAIN II) was modified to incorporate the effect of residual stress. The prediction by the numerical model agreed well with the experimental results.

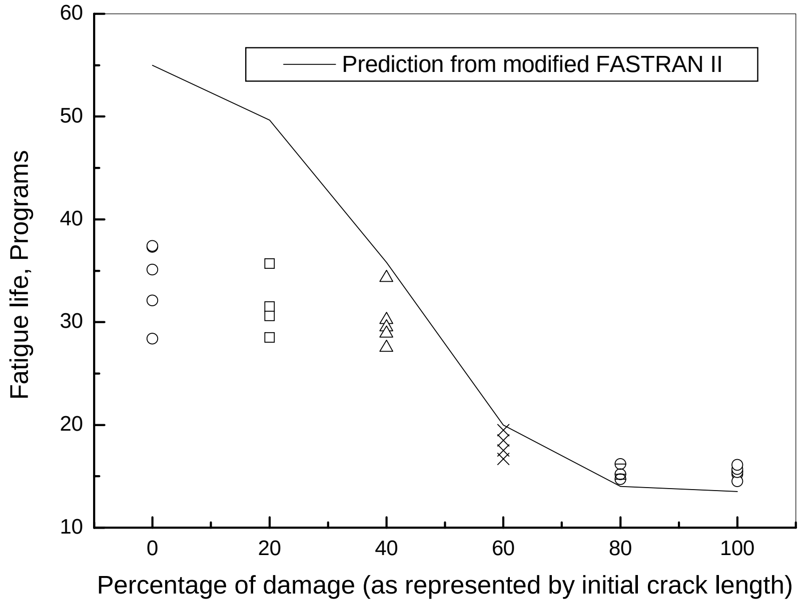



Fig. 6 Comparison of predicted fatigue life for different percentages of prior fatigue damage, using modified FASTRAN II and the experimental data from this study

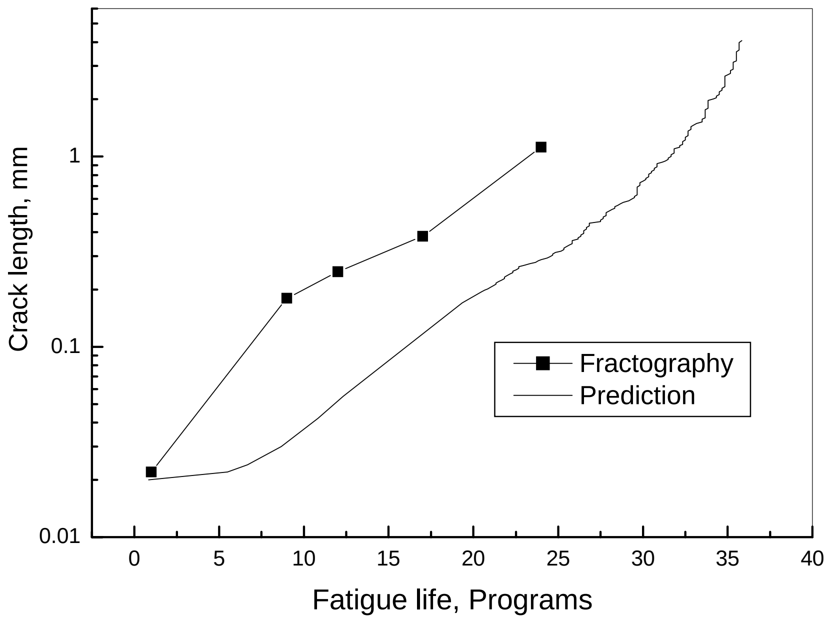



Fig. 7 Predicted crack growth curve for $c_o = 20\ \mu m$ at the 20% of the prior fatigue damage on 7050-T7451 Al material

## ACKNOWLEDGEMENTS

The authors wish to express thanks to Mr. C. Rey and Mr. B. Jones for carrying out the fatigue tests, and Mr. N Goldsmith for his help in conducting fractographic analyses.

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