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Investigating the Benefits of Controlled Shot Peening on Corrosion Fatigue of Aluminium Alloy 2024 T351

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1 Introduction

It is widely accepted that the use of controlled shot peening (CSP) can be a beneficial process to improve the performance of metallic components. More precisely, it is recognised that it can increase fatigue life and reduce susceptibility to stress corrosion cracking (SCC), improvements generally accredited to the induced compressive residual stress layer close to the surface of the shot peened material. These two improvements due to CSP have been reported to be the most commonly investigated [1]. On searching the available literature, works on the effects of CSP on corrosion fatigue are far less in abundance. In most cases CSP was shown to increase corrosion fatigue life by introducing an effective compressive residual stress layer, which reduces crack propagation rates during the early stages of crack growth [2-7]. In one case, CSP was said to have had a greater effect at higher stress levels in a spring steel [8], whilst it has also been shown that the largest gain was achieved at lower stress levels in a structural steel [9]. However, contrary to the aforementioned results, evidence has been presented that shows no advantageous effect of CSP, in either a spring or structural steel, under corrosion fatigue conditions [10].

Possibly due to the mechanical nature of the fatigue phenomenon, very little attention appears to be directed towards the electrochemical effects of CSP. In [3], CSP was seen to have no effect on the free corrosion potential, E_{corr}, in a 1.0N H_2SO_4 solution, but the corrosion current density, I_{corr}, was said to increase with peening. However, in a 3.5% NaCl solution, E_{corr} was seen to be nobler and I_{corr} was reduced. These latter findings are consistent with results observed in [11].

The present investigation has been made as part of an ongoing study into the effects of CSP. Aluminium alloy 2024 T351 is commonly used within the aerospace industry, and is routinely shot peened as part of the manufacturing process. To determine the effects of CSP on the corrosion fatigue behaviour of this alloy, a series of tests were performed. Initially, corrosion fatigue tests were conducted on both unpeened and peened specimens. Electrochemical testing was then undertaken, firstly, to investigate if the shot peening would change the characteristics of the material, and secondly, to help with the interpretation of the corrosion fatigue results.

2 Experimental Procedure

2.1 Corrosion Fatigue

Corrosion fatigue testing was carried out on flat, hourglass profiled specimens of dimensions 200 x 24 x 5mm, with a 10mm wide centre section [Figure 1], in a 3.5% NaCl solution, pH approximately 6.0. The solution was continuously aerated and pumped from a tank to a corrosion cell containing the specimen, and then recycled to the tank throughout the tests. Testing was performed on an Instron 8501 servo-hydraulic test rig at 25 Hz, stress ratio R = 0.1.

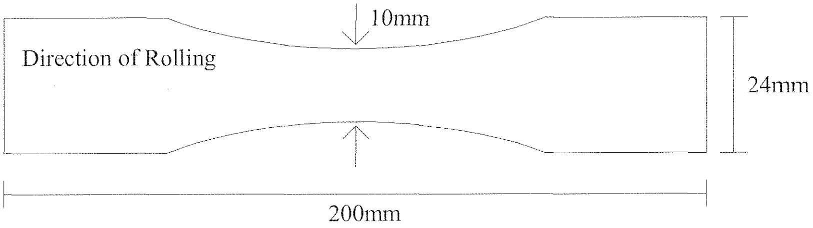

Figure 1: Hourglass specimen for corrosion fatigue testing

Shot peening conditions were 200 % coverage, 45° impingement angle, using steel shot, S110. After peening, the specimens were cleaned using a 70 % nitric acid solution to remove any shot contamination.

2.2 Electrochemical Testing

Electrochemical tests were performed on cylindrical specimens as described in ASTM standard F476-87. Shot peening parameters and solution conditions were identical to those for fatigue testing. Potentiodynamic polarisation tests were conducted to ascertain corrosion characteristics, such as E_{corr} and I_{corr}, by producing Tafel plots (approx ± 600 mV of E_{corr}) and linear polarisation plots (approx. ± 20 mV of E_{corr}).

Observations were made of the peened and unpeened conditions of the alloy's surface after identical periods in the corrosive solution. This was done, using an optical microscope, to com-

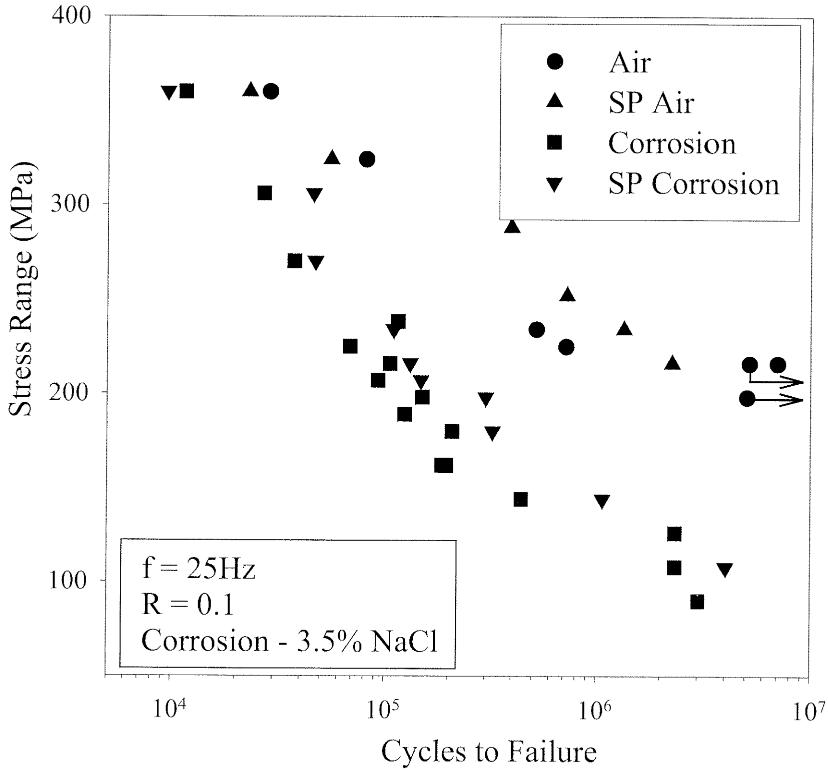

Figure 2: Results of air and corrosion fatigue tests

3.2 Electrochemical Analysis

The free corrosion potential of the material, in both the peened and unpeened conditions, was determined by allowing samples to corrode freely over a number of hours whilst measuring the potential versus a saturated calomel electrode (SCE). The potentiodynamic polarisation tests were then run from approximately –600 mV below this value to +600 mV above it. As seen in Figure 3, in both conditions the material behaves the same. It can be seen that E_{corr} values for the peened specimens, were nobler by about 50 mV.

To determine I_{corr}, it was necessary to determine the polarisation resistance R_p. This can be taken as the gradient of the linear portion of the linear polarisation plot, ±20 mV of E_{corr}. I_{corr} can then be calculated using Equation 1.

$$\frac{\Delta E}{\Delta i} = R_p = \frac{\beta_A \beta_B}{2.3(I_{corr})(\beta_A + \beta_C)} \qquad [1]$$

Where $\Delta V/\Delta i$ is the gradient of the linear portion of the plot, β_A and β_C are the anodic and cathodic Tafel constants respectively, obtained from the polarisation plot, Figure 3.

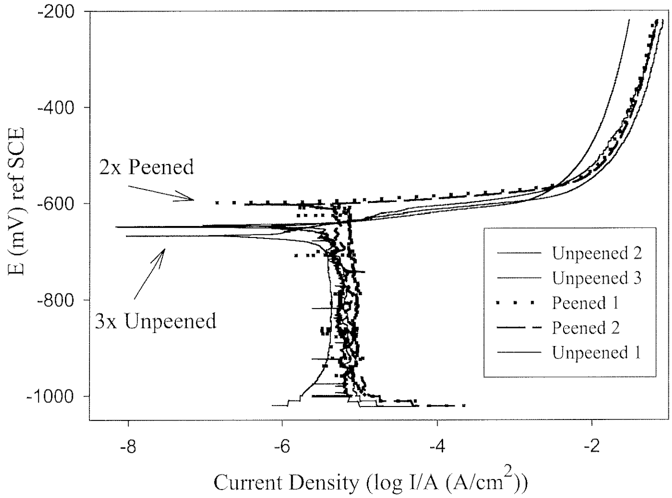

Figure 3: Potentiodynamic polarisation plot indicating the difference in E_{corr}

At least 10 tests were conducted for each condition and the average values of the tests were used for comparison, presented in Table 1.

Table 1: Calculated I_{corr} values for Al 2024 T351

	Unpeened	Peened	Ratio
I_{corr}	0.328 μA	1.719 μA	1 : 5.2

3.3 Optical Microscopy

Surfaces of peened and unpeened specimens were compared after free corrosion for 24 hours, examples are given in Figure 4. The pits in the unpeened material are seen to follow clearly defined lines, or strings of pits, in the direction of rolling. This can be attributed to inclusions, as found in [12], where it was shown that constituent particles, or inclusions, are the primary source for pits, and their locality must be incorporated into probabilistic modelling of pit growth. Such observations are not possible for the peened specimen, and the number of pits is greatly reduced. However, the pits are notably larger, especially perpendicular to the rolling direction, which is the direction of fatigue crack growth.

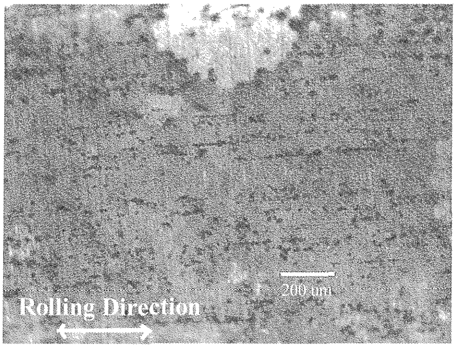

Figure 4a: Unpeened – showing strings of pits in the rolling direction

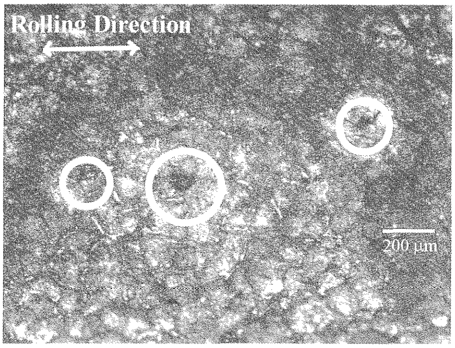

Figure 4b: Peened – showing less, but larger, pits

4 Discussion

As only a slight benefit was obtained from CSP in air fatigue, it is necessary to investigate the role of the compressive residual stresses obtained. Based on a theoretical analysis [13, 14] it is possible to compare the residual stresses developed in the material with those required to overcome the detrimental effects of the indentations created through CSP. The results of this comparison are shown in Figure 5.

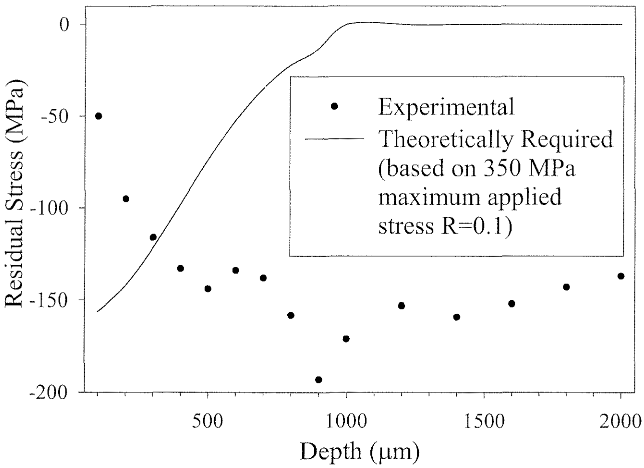

Figure 5: Distribution of residual stresses, measured vs theoretically required

It is demonstrated here, that within approximately 300µm in depth, the residual stresses would not be sufficient to prevent crack growth, however, it might be expected that they would hinder it to some extent. As the early stages of crack growth are known to dominate the fatigue life, it would be expected that having residual stresses higher than those required deeper into he material, would be less efficient in extending the fatigue life.

From the electrochemical analysis, it is observed that CSP can change the pitting characteristics of a material. Although less pits were evident in the peened specimen, the increase in I_{corr} is reflected in the larger size of pit found, thus indicating a higher pit growth rate. An important factor in the larger size of pit is the growth perpendicular to the direction of rolling. The cracks grew in this direction in the tensile specimens. Therefore a crack initiating at a pit of a critical size, and depending on the applied stress level, would initiate earlier due to the increased pit growth rate. As previously stated, the residual stresses would still hinder crack growth, therefore the corrosion fatigue life of the peened material would not necessarily be less than that of the unpeened. It would then be expected that less benefit will be obtained compared to that of CSP for air fatigue, as seen in Figure 2.

Further work is required to quantify the observations made. Crack growth measurements would allow any difference in growth rate be identified and the expected earlier crack initiation in peened specimens be realised.

6 Conclusions

For the peening conditions used, CSP is not effective in extending the corrosion fatigue life of Al 2024 T351.

To gain maximum benefit from CSP, it is necessary to determine the residual stress levels required to produce a given improvement in fatigue life.

If CSP is to be used in corrosion fatigue or SCC conditions, electrochemical analysis should be used to ensure that any changes in pitting characteristics would not be more detrimental than any residual stress benefits gained.

7 References

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