Application of Laser Shock Peening to Aircraft Wing Material to improve Fatigue Performance

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Laser Shock Peening (LSP) is a surface treatment used to induce in materials a near surface compressive residual stress field. It has been shown [1-3] that LSP effectively increases fatigue life, resistance to fretting and resistance to stress corrosion cracking. Compared to the conventional shot peening, greater depth of the compressive residual stress field can be achieved.

Interest in application of LSP to safety critical components in the aerospace industry has increased in recent years however no application has yet been deployed in the airframes of civil aircraft. The primary application of LSP at present is related to critical engine components subjected to high loads, foreign object damage and fretting fatigue; mainly to inhibit crack initiation or the retardation of early crack propagation. The application of LSP on the airframe, characterized by potentially longer cracks, has not been thoroughly investigated.

Therefore the aim of this research was to assess the potential application of laser shock peening to structural components (particularly lower wing skin) and whether it can slow crack propagation and enhance fatigue performance. This has the potential to extend the service life of treated components or alternatively potential weight saving through redesign with incorporation of the benefit of residual stress.

In this work LSP was applied to 2524-T351 M(T) coupons 200×400 mm and 6 mm thick, as illustrated in figure 1. The LSP processing parameters were 3 GW/cm^2 , 5×5 mm spot size, 4 layers of peening with 50% offset between layers. Laser peening was applied into strips either side of the central starter notch and 25 mm from the sample centre line. Two LSP configurations were considered by changing the width of peened strip, as illustrated in figure 1.

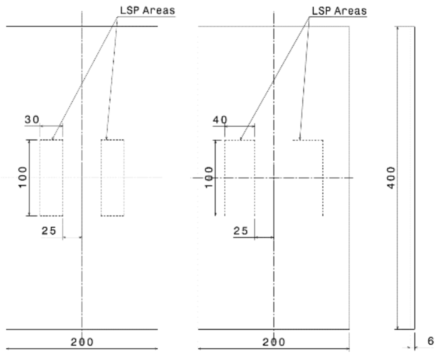

Figure 1. M(T) fatigue coupons indicating location of laser peening strips.

The induced residual stress fields were measured using multiple methods namely incremental hole drilling, contour method and various diffraction techniques. Shown in figure 2 are results from the contour method for the sample peened using a 30 mm LSP strip width. Notice the fully through thickness compressive residual stress field within the peened region. This averaged approximately -150 MPa. However this compression field was balanced by tensile residual stress outside of the peened region.

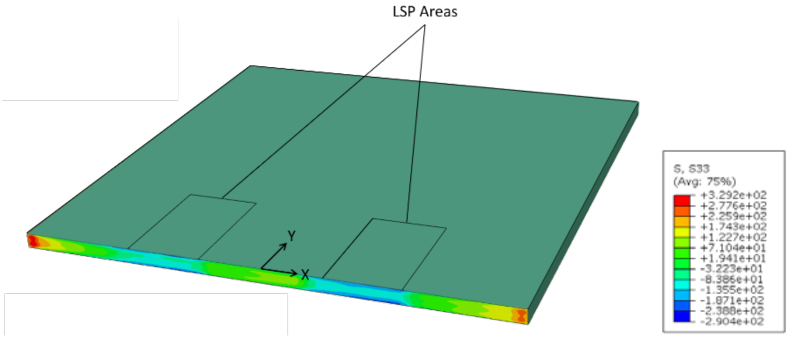

Figure 2. Residual stress field measured using contour method.

The fatigue tests were performed using tension-tension loading with maximum stress 113 MPa and stress ratio 0.1. Shown in figure 3 is a comparison between the fatigue crack growth rate (FCGR) vs crack length 'a' in peened and unpeened samples (note: two samples were tested in each condition but for clarity only one measurement is included). The reduction of FCGR rate, compared to the unpeened case, as the crack enters the peened area is clearly evident in figure 3. This is due to the LSP induced compressive residual stress field. As the crack leaves the peened region the FCGR increases again with crack extension.

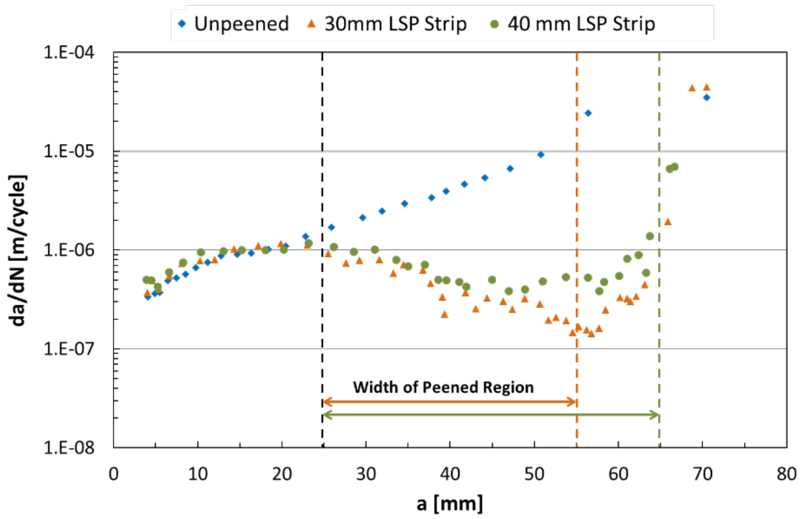

Figure 3. Comparison of fatigue crack growth rate vs ΔK in the peened and unpeened conditions.

However not as noticeable is the increased FCGR, compared to the unpeened case, prior to the crack entering the peened region. This increase is due to balancing tensile residual stress outside the peened area. The factor of life improvement compared to the unpeened case was 3.9 for the samples peened using a 30 mm LSP wide strip but only 2.2 for samples peened using a 40 mm LSP wide strip despite the larger coverage area. Although peeing using a greater coverage does induce more compression within the peened area, it requires greater tension outside of it to maintain equilibrium.

These results imply that an optimum peening strategy exists in terms of peening coverage and location, independent of the peening process parameters (i.e. laser power, spot size etc.). Indeed an FE based modelling approach was developed to predict the measured FCGR rates and good agreement was achieved compared to experimental measurements [4]. Using this model a parametric analysis was used to determine an optimal configuration to maximize fatigue performance. For the specific configuration tested the predicted optimum was a 20 mm wide LSP strip located 15 mm from the sample centre line.

The results of this work clearly show the potential benefit in fatigue performance that can be achieved through the use of LSP on safety critical components and structures. However it also highlights the need to carefully consider the peened area location and size specific to the component being treated in order to control the balance between the beneficial compressive residual stress induced with the balancing tensile residual stress.

Keywords: Laser Shock Peening, Fatigue, 2524-T351 Aluminium

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