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# Fatigue crack propagation in shot peened al 7475-t7351 alloy specimens

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**Abstract**

The approach to engineering design based on the flaws propagation assumption applying the principles of fracture mechanics is commonly used in aluminum structures for aerospace engineering, in which surface shot peening is an attractive method of improving fatigue performance, because it promotes the retardation of the crack initiation and earlier crack growth. The main purpose of present work was to analyze the effect of the surface shot peening on the fatigue crack propagation of the 7475 aluminum alloy with a T7351 heat treatment.

Two types of fatigue tests were performed: constant amplitude and variable amplitude loading in which periodic overload blocks of 300 cycles are applied with intervals of Nint cycles. Surface micro shot peened promoted an increasing in micro-hardness only in order or 6% and created negative surface residual stresses in order of -174 MPa, which compare with the positive residual stresses of +291 MPa on the machined specimens.

For tests at constant amplitude loading the effect of surface peening on da/dN-ΔK curves is quite limited, particularly for R = 0.4. However, this beneficial effect increases significantly near the threshold. Repeated overload block reduces significantly the fatigue crack propagation rate, being this effect particularly dependent of the intervals between the blocks. The maximum reduction of crack propagation rate and retardation effects were obtained for Nint = 7500 cycles.

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## 1. Introduction

One of the principal problems in contemporary aircraft industry is to ensure simultaneously reliability, high durability, minimum weights and economic efficiency of transport airplanes. In order to get such characteristics, it is required to ensure structural damage tolerance at the design stage of aircraft. The approach to engineering design based on the assumption that flaws can exist in any structure and propagate with usage is commonly used in aerospace engineering, managing the extension of cracks through the application of the principles of fracture mechanics. Therefore, the prediction of crack growth rates once a macroscopic crack has nucleated is, of course, an important aspect of a damage tolerant assessment of component life.

Since the majority of fatigue cracks initiate on the surface, the conditioning of the surface to resist crack initiation and earlier crack growth is an attractive way to improve fatigue performance. Shot peening is a widely used for this purpose in metallic components. Positive effect of shot peening was proven by many works of researchers [1-3], commonly accredited to introduction of compression residual stresses in the subsurface layers of material. Depending of the peened alloy there is an Almen intensity for which the optimum fatigue strength is achieved, corresponding to a certain compressive residual stress field surface roughness damage.

The fatigue crack growth of the aluminum alloys in the Paris regime is affected by microstructure and by the crack closure induced by plasticity, oxidation and surface roughness (in the near threshold regime). The influence of mean stress on the fatigue crack growth rate has been explained with success by the crack closure. Bergner and Zouhar [4] showed that crack growth rates of various aluminium alloys varied by a factor of about 20 at some values of $\Delta K$, suggesting that the mainly factor to explain that discrepancies was the effects of crack closure and environment.

Overloads can lead to significant interaction effects on crack propagation, as have been reported in many investigations [5-9]. Several mechanisms have been proposed to explain crack growth retardation; including models based on residual stresses, crack closure, crack tip blunting, strain hardening, crack branching and reversed yielding. The effect of residual plastic deformation leads to compressive stresses before the crack tip and raises the crack opening load on subsequent crack growth (crack closure), becoming the most important aspect in explaining the variation of the characteristic features of post-overload transients [7]. Borrego et al. [10] concluded that crack closure was able to explain the influence of the stress ratio on the fatigue crack growth rate for the 6082-T6 aluminium alloy and the influence of several load parameters for overloads interactions.

The present work intends to analyze the effect of the surface shot peening, the specimen thickness and the stress ratio on the fatigue crack propagation of the 7475 aluminum alloy with a T7351 heat treatment. Also a more extensively analysis of the crack growth following repeated tensile overloads with different overload ratios will be evaluated.

## 2. Materials and experimental procedures

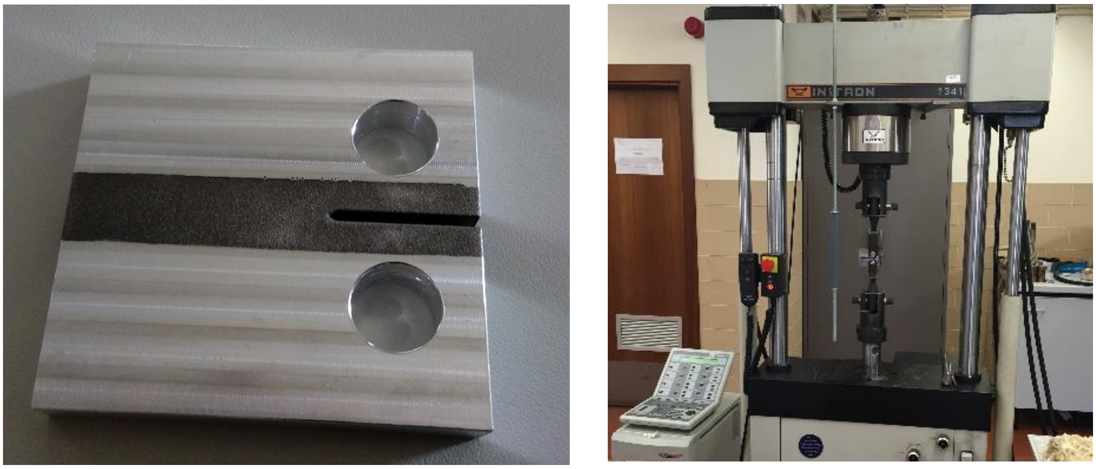
This research was conducted using the 7475 aluminum alloy with a T7351 heat treatment, which widely used in aeronautical applications where the combination of high strength and fracture toughness and also good resistance to fatigue crack propagation and corrosion are required. The chemical composition of the alloy, according the manufacturer, is indicated in table 1.

Table 1. Chemical composition of the 7475-T7351 aluminum alloy [% Weight].

| Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Outros | Al |
|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 0.12 | 1.2-1.9 | 0.06 | 1.9-2.6 | 0.18-0.25 | 5.2-6.2 | 0.06 | 0.15 | Remaining |

Two batches of samples were prepared: A reference batch of ground and polished specimens (MPL) and other with micro shot peened surfaces (MSP). These specimens have been surface peened in crack propagation region (as illustrated in Fig. 1a), using cast steel shot S170, according to the specifications and recommendations on ASM 2430 standard for the shot peening of aluminium alloys. Shot peening was done in OGMA, Indústria Aeronáutica de Portugal S.A., using a SURFATEC machine, and with an Almen strip type A. The samples were manually rotated in order to promote the impact angle of the beads on surfaces about 90º in all zones. Coverage was assessed by visually inspecting the surface, using a 10x magnifying lens. The coverage is achieved at 100% when this analysis shows a surface completely attained by the particles. Almen intensity was 0.0074 mmA, according ASM 2430 standard.

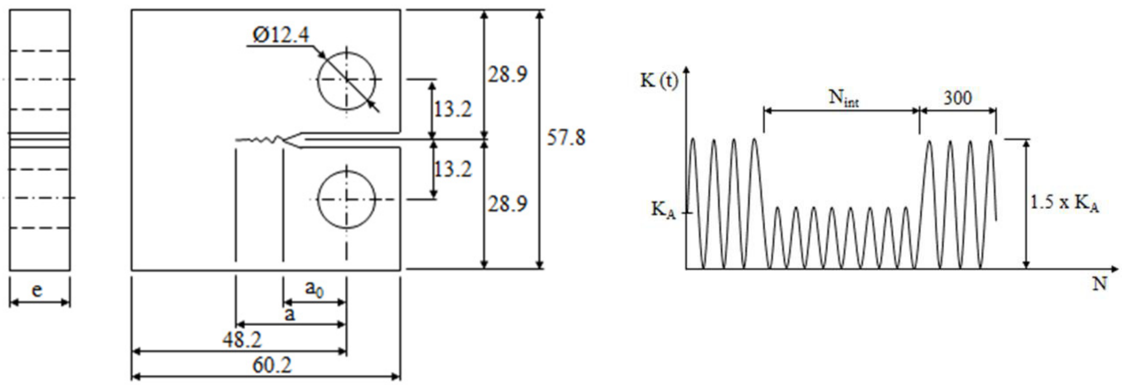
Uniaxial fatigue tests were performed in order to obtain curves of the crack length against the number of cycles, N, using a servo-hydraulic Instron 1341 (shown in Fig. 1b) equipped with a load cell, which has a maximum capacity of 100 kN, interfaced to a computer for machine control and data acquisition.




a) b)

Fig. 1. (a) Shot peened sample; (b) Fatigue machine apparatus.

Fatigue tests were carried out, in agreement with ASTM E647 [11] standard, using 8 mm thick compact specimens (CT). The specimens were obtained in the longitudinal transverse direction from laminated plates. Fig. 2a) illustrates the major dimensions of the samples used in the tests. All tests were conducted in load control mode, in air and room temperature, at a frequency of 15-20 Hz. They were performed two types of tests: constant amplitude loading with the stress ratio R=0.05 and 0.4 and variable amplitude loading in which periodic overload blocks of 300 cycles were applied with intervals of Nint cycles as is shown schematically in Fig 2 b).




a) b)

Fig. 2. Geometry and dimensions of the samples; (b) Overload block loading.

The crack length was measured using a travelling microscope (45X) with accuracy of 10 μm. Complementary, and for the surface peened specimens, the crack length was obtained by using an experimental calibration curves based on the compliance variation. Taking in account the compliance definition, given by Equation (1).

$$C=\frac{(u_{máx}-u_{mín})}{(P_{máx}-P_{mín})} \quad (1)$$

where u and P are the displacement and the load of the cycle, respectively, which were monitored during the test. From the non-peened specimen tests with constant amplitude loading it was monitored a set of data for C and the correspondent values of the crack length. These data are plotted in Fig. 3, in terms of the crack length (in mm) versus the compliance, and were fitted by the equation (2), with a correlation factor of 0.99. This equation was afterwards used for the evaluation of the crack length in the tests on peened specimens with constant amplitude loading and in the tests with overloads.

$$a=39515\times C^5-53199\times C^4+27962\times C^3-7278,2\times C^2+980,36\times C-23,559 \quad (2)$$

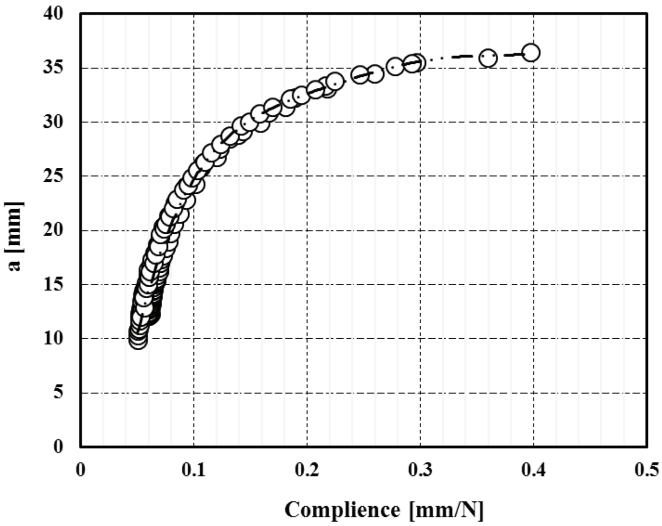



Fig 3: Compliance calibration curve.

The surface roughness was evaluated according to DIN EN ISO 4288 standard using the rugosimeter Surftest SJ-500 Mitutoyo. The parameters evaluated for each superficial treatment were: roughness average Ra, root mean square (RMS) roughness Rq and mean roughness depth Rz. An increasing in the three roughness parameters more than 200% for the peened surfaces was observed.

One sample with micro shot peened surface was cut through the cross section. Afterwards, the surfaces were gradually polished with smaller granulometry silicon carbide papers, and at the end diamond particles with a 1 μm diameter were used until it became a mirror-like surface. Then, those surfaces were etched with Keller reagent (2,5% $HNO_3$; 1,5% HCl; 1% HF; 95% $H_2O$ [volume]). The optical microscope Leica DM 4000 M LED was used to photograph the etched surfaces. Fig.4) shows a micrograph showing that base material microstructure consists of grains elongated in the rolling direction and a slight grain refinement close to the surface.

Surface Vickers hardness testing was performed according to ASTM E384-99 using a Struers Duramin 1 microhardness tester with a 0,1 Kg load for 15 seconds. The average values obtained in the longitudinal mean line in points spaced 0.5 mm from each other, were: Hv0.1=157 for MPL surfaces and Hv0.1=167 for MSP surfaces. Micro shot peened increased surface hardness in order or 6%.

Surface residual stresses determination was carried out by X-Ray diffraction using the sin2ψ method with Proto iXRD equipment. Measurements were made for all studied treatments at 4 points along the surface of one specimen. The average values obtained, were: +291 MPa for MPL surfaces and -174 MPa for MSP surfaces.

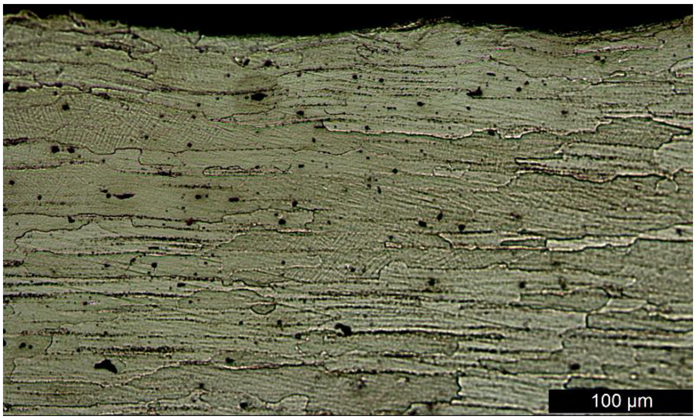



Fig. 4. Microstructure of MSP specimens.

## 3. Fatigue results

Fatigue crack growth was evaluated in terms of the da/dN – ΔK curves. Fig. 5 shows the effect of the surface peening on the da/dN – ΔK curves for tests performed with the values of R of 0. 05. As expected the surface shot peening have a negligible effect on da/dN crack rate for long size cracks. However, for the stress ratio R=0.05 and small crack sizes (near the threshold) surface peening trends to reduce crack propagation rate and increasing threshold value.

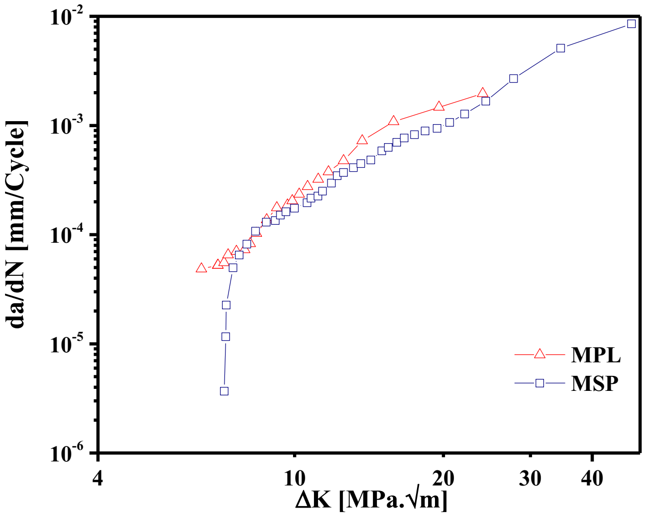



Fig. 5. Effect of the shot peening on the da/dN – ΔK curves; 8mm thickness, R=0.05.

The influence of the stress ratio on the fatigue crack growth rate can be seen in Fig. 6, for the shot peened specimens, considering the values of R of 0.05 and 0.4. Similar behavior was observed for reference non-peened samples. As well reported for aluminium alloys a significant effect of the stress ratio was observed. In case of the shot peened samples, also a significant decrease of the threshold values and an important increase of crack growth rate in stage I, was obtained for R=0.4, widely justified by crack closure reduction.

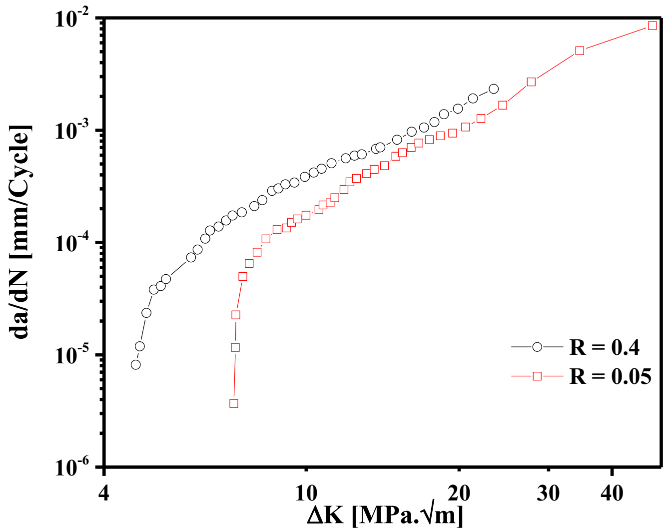



Fig. 6. Effect of the mean stress on the da/dN – ΔK curves; 8mm thickness, MSP samples.

Fig. 7 illustrates fatigue crack propagation, da/dN – ΔK curves, obtained from tests in which periodic overload blocks of 300 cycles were applied with intervals of Nint cycles (as is shown in Fig 2 b)). These curves show that both for Nint = 7500 and 15000 cycles, important reductions of crack propagation rate were obtained, particularly for low stress intensity factor ranges. The higher benefit reductions were observed for Nint = 7500 cycles. The typical transient crack growth behaviour following tensile overloads were not clearly observed, due to a lack of accuracy of measurement system used and the interval between measures. However, for low stress intensity factor ranges it was possible to observe, the typical retardation immediately after the overload, assumed to be caused by high plasticization.

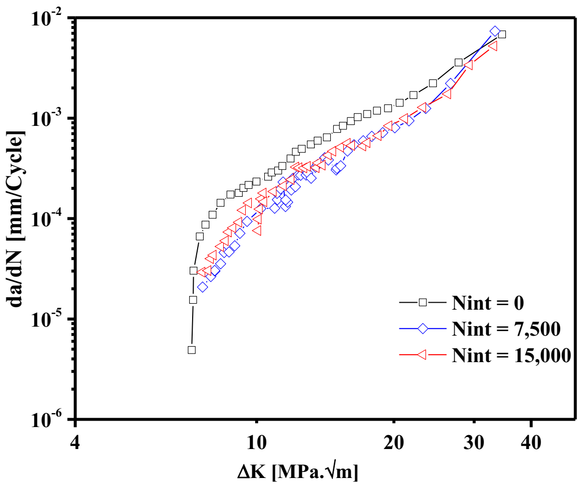



Fig. 7. Effect of overloads on the da/dN – ΔK curves; 8mm thickness, MSP samples.

Fracture surface analysis was performed with a scanning electron microscope (Philips XL30). Fig. 8) shows the crack propagation from the straight notch. Some precipitates are visible inside the base material: Fatigue crack propagation is accompanied by a significant material plasticization.

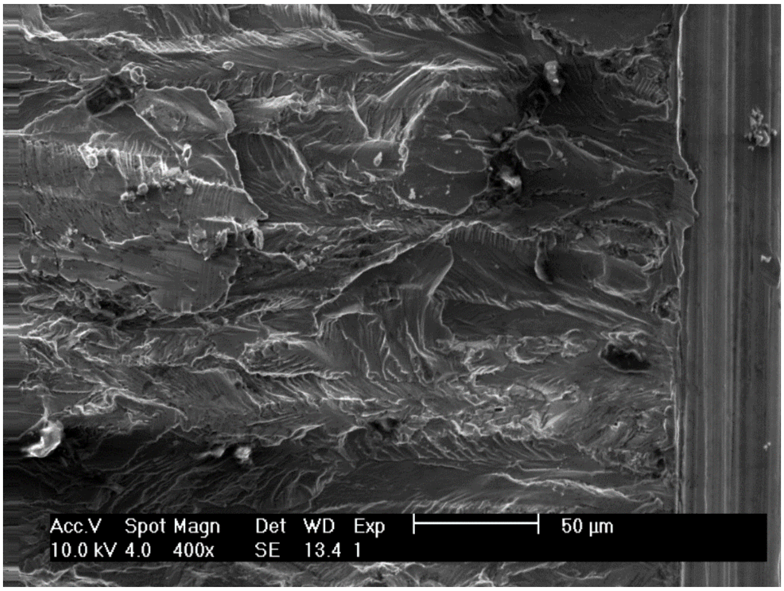



Fig. 8. SEM observation in notch region.

## 4. Conclusions

The effect of the surface shot peening on the fatigue crack propagation of the 7475 aluminum alloy with a T7351 heat treatment was analyzed for specimens with 8 mm thickness. The main conclusions are:

- For tests at constant amplitude loading the beneficial effect of surface peening on da/dN-ΔK curves is quite limited, particularly for R = 0.4. However, this effect increases significantly near the threshold;
- A significant effect of the mean stress was observed;
- Repeated overload block reduces significantly the fatigue crack propagation rate, being this effect particularly dependent of the intervals between the blocks. The maximum reduction of crack propagation rate and retardation effects were obtained for Nint = 7500 cycles.

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