Consideration of Shot Peening Treatment Applied to a High Strength Aeronautical Steel with Different Hardnesses

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1 Introduction

One of the most important components in a aircraft is its landing gear, due to the high load that it is submitted to during, principally, the take off and landing. For this reason, the AISI 4340 steel is widely used in the aircraft industry for fabrication of structural components, in which strength and toughness are fundamental design requirements [1]. Fatigue is an important parameter to be considered in the behavior of mechanical components subjected to constant and variable amplitude loading. One of the known ways to improve fatigue resistance is by using the shot peening process to induce a compressive residual stress in the surface layers of the material, making the nucleation and propagation of fatigue cracks more difficult [2,3]. The shot peening results depend on various parameters. These parameters can be grouped in three different classes according to R. Fathallah et al [4]: parameters describing the treated part, parameters of stream energy produced by the process and parameters describing the contact conditions. Furthermore, relaxation of the CRSF induced by shot peening has been observed during the fatigue process [5-7]. In the present research the gain in fatigue life of AISI 4340 steel, obtained by shot peening treatment, is evaluated under the two different hardnesses used in landing gear. Rotating bending fatigue tests were conducted and the CRSF was measured by an x-ray tensometry prior and during fatigue tests. The evaluation of fatigue life due the shot peening in relation to the relaxation of CRSF, of crack sources position and roughness variation is done.

2 Experimental Work

The chemical composition of AISI 4340 used is 0.41C-0.73Mn-0.8Cr-1.74Ni-0.25Mo-0.25Si, weight percent. The mechanical properties of base material from the 53HRC are: yield strength 1511 MPa, ultimate tensile 1864 MPa. These properties were obtained by means of quenching from 815 °C followed by double tempering in the range (230±5) °C for 2 hours. The mechanical properties of base material from the 39HRC are: yield strength 1118 MPa, ultimate tensile 1240 MPa. These properties were obtained by means of quenching from 815°C followed by tempering in the range (520±5) °C for 2 hours. Shot peening treatment was performed with steel shot in 0.008A peening intensity. This Almen intensity was adopted for the following reason: in the previous studies this peening intensity when applied on surface of AISI 4340 steel prior to the hard chromium plating resulted in significant recovering of fatigue strength. [8]. In the 53HRC condition, the effect of the shot peening pre treatment of hard chromium plated AISI 4340 steel, in the same intensity, was still better. The process parameters were: outflow 3 kg/min, speed 250 mm/min, distance 200 mm and rotation 30 rpm, shot S230 (∅ 0.7mm), coverage 200 %

carried out with an air-blast machine according to standard MIL-S-13165. The shot peening treatment was done with high quality control, in which the shots are automatically selected and kept in perfect conditions. The specimens used were tested in rotating bending fatigue tests at frequency of 50Hz at room temperature (Figure 1). The fracture planes of the fatigued specimens were examined using a scanning electron microscopy model LEO 435 Vpi in order to identify the crack initiation points. The compressive residual stress field induced by shot peening was determined by x-ray diffraction method, using the Raystress equipment, whose characteristics are described in [9]: y goniometer geometry, Cr-k_{α} radiation and registration of {221}diffraction lines. The accuracy in the stress measurements was $D\sigma = \pm 30$MPa. In order to obtain the stress distribution by depth, the layers of specimens were removed by electrolytic polishing with a non-acid solution. All surface roughness data measured in this research was obtained by Mitutoyo 301 equipment using a cut-off of 0.8 mm.

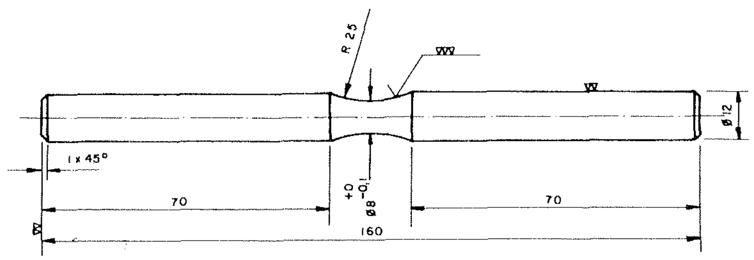

Figure 1:- Rotating bending fatigue test specimen (mm)

3 Results And Discussion

Figure 2 shows the Compressive Residual Stress Field (CRSF) for the 0.008A peening intensity for both 39 and 53HRC (solid lines). It is possible to observe, from Figure 2, that the surface stress and the depth of CRSF for 39HRC were lower than 53HRC condition. These results were expected, since the surface stress and the maximum value of the CRSF beneath the surface are a function of the yield strength and ultimate strength, respectively. However, the width of CRSF for 39HRC was a little bigger than 53HRC one. Since the width of CRSF is actually the plastic deformation depth, it is possible to suppose that the smaller hardness the larger the affected layer. The S/N curves for the base material and with shot peening treatment with 53 and 39HRC condition are shown in figures 3 and 4 respectively. It is possible to observe in figure 3 an improvement in the fatigue resistance of the specimens shot peened, compared to the base material. In relation to the base material, the shot peening influence in high stress (1370MPa) was almost null in the number of cycles until failure, for medium and high cycles an increase in fatigue life resulted from the shot peening treatment. Yet, the shot peening for the 53HRC condition represents an enhancement of the fatigue limit about 10% when comparing to the base material. For intermediate conditions (10^5-10^6 cycles) however, the fatigue gain in relation to the base material was much more expressive, about three times. Figure 4 shows that, surprisingly, there is not gain in fatigue life as a consequence of the shot peening treatment when applied to specimens 39HRC, for all stress levels studied. According to previous studies [7], the effects of CRSF induced by the shot peening treatment on fatigue life gain is due to two different mechanisms, which act simultaneously. The first mechanism considers that the CRSF pushes the crack source beneath the surface of the base material, resulting in larger crack nucleation period and, consequently, larger fatigue life of a component. The second ones consider that the CRFS delays the nucleation/propagation process from superficial crack sources, increasing the fatigue life as well. The factors controlling crack origin at the surface or below the surface are a function of: CRSF dimensions, stress applied by fatigue tests and roughness generated by

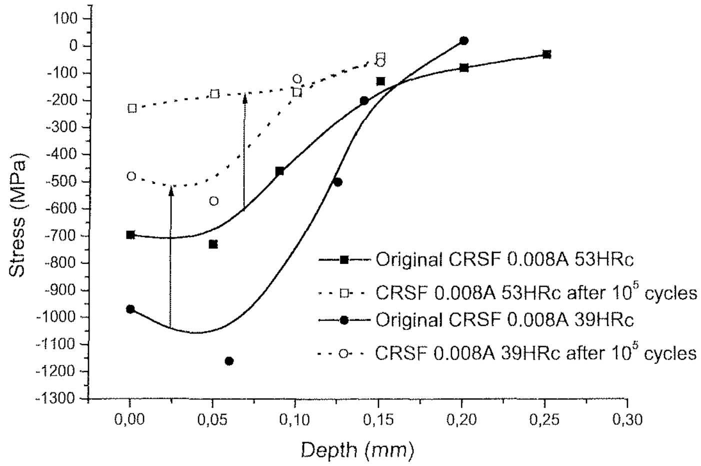

Figure 2: Compressive residual stress field produced by 0.008A peening intensity in two hardnesses prior and after cyclic loading (10^5 cycles)

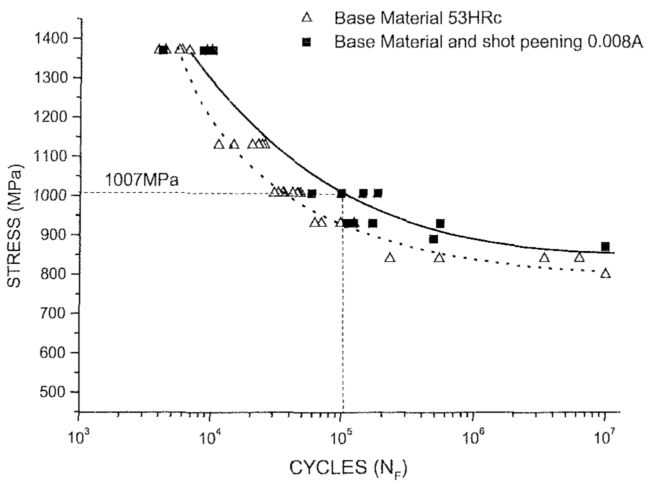

Figure 3: Fatigue results of AISI 4340 steel with and without shot peening with 0.008A and 53HRC

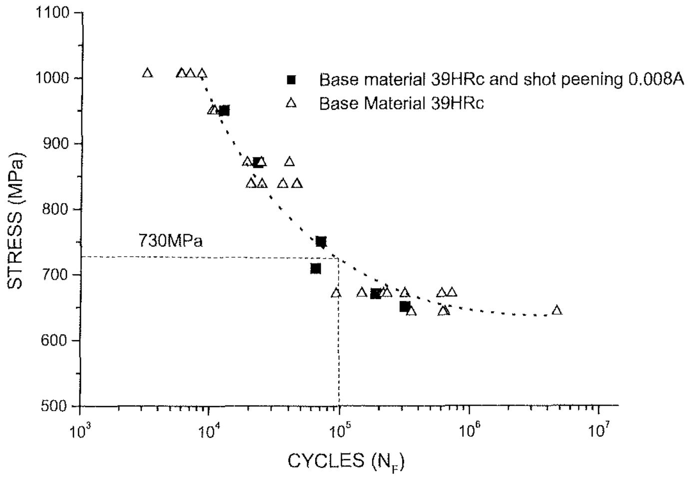

Figure 4: Fatigue results of AISI 4340 steel with and without shot peening with 0.008A and 39HRC

the shot peening treatment. Moreover, it was observed that despite both mechanisms caused an increase in fatigue life of a component, the first one is more efficient [7]. Therefore, it is desirable that the shot peening treatment is capable of pushing the fatigue life crack nucleation below the surface. It is also known that the shot peening intensity results in an increase in the maximum compressive residual stress and the width of the CRSF, but the stress at the surface is maintained almost the same [10,11]. On the other hand, the increase of the shot peening intensity causes the roughness to increase due to larger cavities created by the impact of the shot, which results in faster fatigue crack nucleation when the crack source is from the surface. Therefore, it is necessary to achieve a balance of this variable in order to obtain a good performance of the shot peening process. Due to this fact, researchers have obtained better fatigue results by using intermediate shot peening intensity [7,12]. Shot peening intensities which balance a CRSF with enough dimensions to push the crack source below the surface or to delay its nucleation/propagation in surface cracks due to the more positive surface conditions, are more adequate in obtaining a greater gain in fatigue life. Table 1 presents the increase of roughness as a consequence of the shot peening treatment used in this study. It is possible to observe that the both initial (before shot peening) and final roughness (after shot peening) were larger for specimens 39HRC than specimens 53HRC. By considering that the material is softer it is subjected to larger superficial deformations, which cause the roughness to increase.

Table 1: Roughness results

AISI 4340	Without shot peening	With shot peening 0.008A
39HRC	0.08 ±0.021μm	1.34 ±0.095μm
53HRC	0.22 ±0.016μm	0.92 ±0.063μm

It was observed, in a previous work, that the fatigue strength in the AISI 4340 steel was quite sensitive to the roughness variation. In this research a roughness variation from 0.1 to 1.5μm produced by sandpaper was made and as a result, the fatigue strength in rotating bending tests decreased approximately 60% to low cycle and 90% to high cycle [13]. Although the roughness variation created by shot peening and sandpaper were originated from different situations, the reduction in fatigue strength due to the increase of the roughness induced by the shot peening was expected. Due to the fact that there was not a reduction in fatigue strength of specimens 39HRC shows the performance of CRSF induced by the shot peening treatment. For specimens 53HRC, the fatigue strength gain allows us to speculate about a more appropriate correlation between roughness and CRSF generated by the shot peening process. However, the CRSF can suffer variations under cyclic loading. Many authors studied this subject and they showed that, usually, the CRSF suffers a decrease in the absolute stress value during the fatigue process [5,7]. This stress relaxation is directly related to the applied stress and the number of cycles to which the specimens are subjected [6,7]. For the study of the reported situation, additional tests were performed to verify the possible variation of the residual stresses induced by shot peening under cyclic loading. In these tests, the specimens were subjected to cyclic loading and removed from the rotating bending machine before failure occurred, and then, the new CRSF was measured. The measurements were carried out in 10^5 cycles, in which the greatest gains in fatigue life for the 53HRC condition could be observed (figure 3). Figure 2 shows the relaxation of CRSF after 10^5 cycles for both hardnesses studied (dot lines). It can be observed that the decrease of the CRFS was significant enough for both. This stress relaxation is justified when in the rotate bending fatigue test the compressive stress applied is added to the local compressive residual stress induced by shot peening. If the result of this superposition is big enough, there will be a plastic deformation and consequently a rearrangement of the stresses, causing relaxation of the original CRSF [5].Table 2 shows the residual stresses values at the surface produced by shot peening treatment prior and after fatigue tests (10^5 cycles). For the 53HRC condition, the rate between applied stress in fatigue tests and the residual stress after10^5 cycles was smaller than 39HRC condition (column F). Before cyclical loading, the ratio between the applied stress and residual stress at the surface was approximately the same for both hardnesses. So, it is expected that after 10^5 cycles the CRSF is more efficient in avoiding the crack nucleation at the surface for specimens 53HRC than specimens 39HRC. In addition, the algebric sum of the applied stress and residual stress after 10^5 cycles was, approximately, the same (table2, column E). Therefore, for the 53HRC specimens, the crack source from the surface would have a higher possibility to have its nucleation delayed, since with a greater hardness and smaller roughness the material has bigger fatigue strength with same applied stress.The fracture surface of fatigue specimens can prove the previous considerations. The shot peening treatment pushes the crack sources beneath the surface in most of medium and high cycles cases for the 53HRC showing the CRSF influence (figure 5). All the specimens with shot peening in low cycle or without shot peening had their cracks originated from the surface. This fact can be explained since the high applied tension stresses always significantly surpass the residual stresses induced by the shot peening process in case of low cycle conditions with and without stress relaxation. In specimens without shot peening it is natural that the crack source comes from the surface, where the maximum tension stress occurs, induced by the test characteristics. For the specimens 39HRC, with and without shot peening treatment, all the cracks originated from the surface, indicating a lower performance of the CRSF induced by the process.

Table 2: Residual Stress values at the surface (MPa)

AISI 4340	A	B	C	D	E	F
Hardness	Applied Stress	Original Residual Stress	A/B	Residual Stress after 10^5 cycles	A + D	A/D
53HRC	1007	-970	1,04	-480	527	2,02
39HRC	730	-697	1,05	-230	500	3,17

4 Conclusions

Some of factors that influence the fatigue life with the shot peening process are: the capacity of the CRSF of pushing the crack source to beneath the surface or not, the increase of roughness variation induced by shot peening process and the relaxation of the CRSF due to cyclic loading.Due the favorable combination of above factors, the shot peening intensity of 0.008A resulted in an increase of fatigue strength of 53HRC specimens. For other hand, the same intensity of shot peening did not produce fatigue strength variation for 39HRC.

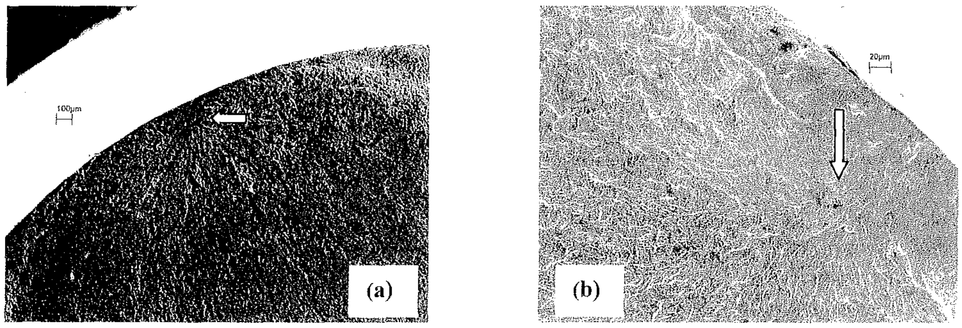

Figure 5: Detail of crack source beneath the surface: a) Applied stress =931MPa; N_F = 552900 cycles; crack source = 225µm from the surface; b) Applied stress =1007MPa; N_F = 98600 cycles, crack source = 72µm from the surface.

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