ANALYSIS OF THE INFLUENCE OF SHOT PEENING ON THE FATIGUE LIFE OF A HARD CHROMIUM ELECTROPLATED AISI 4340 STEEL UNDERPLATE

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ABSTRACT

Hard chromium plating is widely used on AISI 4340 landing gears to obtain high levels of resistance against wear and corrosion. However, it causes a reduction in the fatigue strength of the components. In order to increase the fatigue resistance of chromium electroplated steel, a shot peening treatment was applied before coating deposition. This treatment introduces compressive residual stresses in the coating/substrate interface in order to make more difficult the crack propagation from the chromium plating into the base material. In the present research, the effect of shot peening in fatigue life of AISI 4340 steel, tempered to the two different hardnesses used in landing gear, is evaluated by rotating bending fatigue tests. To support the fatigue result analyses, the compressive residual stress fields were measured by x-ray tensometry, prior and after fatigue tests in order to analyze its relaxation. In addition, the surfaces of fractured fatigue specimens were investigated.

SUBJECT INDEX

Fatigue, Residual Stress, Stress Relaxation, Hard Chromium,

INTRODUCTION

The reasons for the reduction of fatigue strength by hard chromium plating may be due to several factors (Jones, 1989; Nascimento, 2001,2002): high tensile residual stresses originated during the electrodeposition, the existence of microcracks in chromium, substrate hardness, the chromium plating thickness, the parameters used in electrodeposition, and the strong coating/substrate interface adhesion. Some of theses factors will be discussed in this work for a 100μm hard chromium coating, applied to AISI 4340 with 39 and 53HRC hardnesses (Brazilian Aircraft Industry parameters). In previous works it was demonstrated that the shot peening intensities ranging from 0.0060 and 0.0085 A produce the best gain in fatigue life, when applied to AISI 4340 steel with 53HRC Hardness (Torres, 2002). Furthermore, relaxation of the Compressive Residual Stress Field (CRSF) induced by shot peening has been observed during the fatigue process (Kodama, 1972; Bignonnet, 1987). This stress relaxation is justified when in the 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. With continuous cycling and due to the stress relaxation, the algebraic addition of the stresses will decrease. At a certain time, it is possible that the superposition of the stress stays below the cyclic yield strength, so the CRSF can become stable (Bignonnet, 1987; Torres 2002, 2003). In this work the reduction of fatigue strength in 4340 steel is evaluated when submitted to chromium plating. In order to restore the fatigue strength, a shot peening treatment with 0.0063 and 0.0083A, before the chromium electrodeposition for a 53HRC hardness and a 0,0083A for a 39HRC hardness, is recommended. The effects of shot peening were investigated by rotating bending fatigue tests. The CRSF was measured with and without chromium plating to analyse the likely effect of coating in residual stress field induced by the shot peening process. In addition, the CRSF was once more measured after 10^7 fatigue cycles to verify if there is any relaxation effect when a pre-treatment of shot peening is applied between chromium plating and substrate. In order to obtain information about the fatigue crack behaviour, the fractured fatigue specimens were investigated using a scanning electron microscope.

EXPERIMENTAL WORK

The chemical composition of AISI 4340 used is 0.41C-0.73Mn-0.8Cr-1.74Ni-0.25Mo-0.25Si (all numbers in weight percent). The mechanical properties of the base material with 53HRC are: yield strength 1511MPa, ultimate tensile strength 1864MPa. These properties were obtained by means of quenching from 815°C followed by double tempering in the range (230±5)°C for 2 hours. A shot peening treatment was performed with steel shot in 0.0063 and 0.0083A peening intensities. The mechanical properties of the base material with 39HRC are: yield strength 1118MPa, ultimate tensile strength 1240MPa. These properties were obtained by means of quenching from 815°C followed by tempering in the range (520±5)°C for 2 hours. A shot peening treatment was performed with steel shot and peening intensity of 0.008A. The process parameters were: outflow 3 Kg/min, speed 250mm/min, distance 200mm and rotation 30rpm, 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 hard chromium electroplating was accomplished in a bath of solution of chromic acid with 250 g/l of CrO_3 and 2,5 g/l of H_2SO_4 at 50 – 55°C, with a current density from 31 to 46 A/dm^2, and speed of deposition at 25μm/h. A bath with a single catalyst based on sulfate was used. After the coating deposition, the samples were subjected to a hydrogen embrittlement relief treatment at 190°C for 8 hours. The specimens were tested in rotating bending fatigue tests at frequency of 50Hz at room temperature (fig.1). The fracture surfaces of the fatigued specimens were examined using a scanning electron microscopy model LEO 435Vpi in order to identify the crack initiation points. The compressive residual stress field induced was determined by the x-ray diffraction method, using the Raystress equipment, whose characteristics are described in (Gurova, 1997): φ goniometer geometry, Cr-Kα radiation and registration of {211} diffraction lines. The accuracy in the stress measurements was $\Delta\sigma$ = ±30MPa. In order to obtain the stress distribution by depth, the layers of specimens were removed by electrolytic polishing with a non-acid solution.

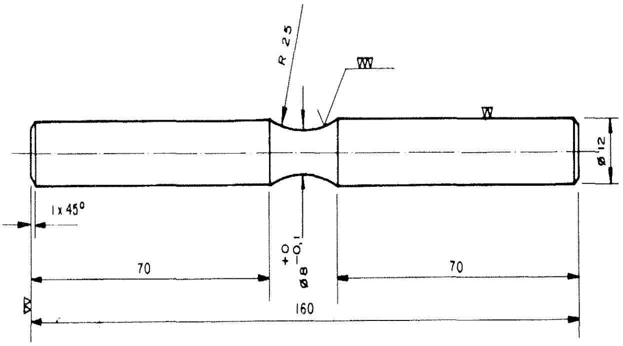

Figure 1 – Rotating bending fatigue test specimen.

RESULTS AND DISCUSSION

Figures 2 and 3 show the fatigue curves of AISI 4340 steel with a hardness of 53 and 39HRC respectively, with and without chromium plating. In both cases it is possible to observe a reduction in the fatigue strength caused by the chromium plating. In figures 4 and 5 the existence of tensile stresses in the coating for both hardnesses studied (curves 4A and 5A) is evident as expected (Durut, 1998). A further analysis of stress development in the chromium plating will be discussed in another paper. However, it is important to note the existence of compressive stresses in the interface and in the first layers of the substrate (curves 4A and 5A). These stresses come as a result of a stress balance, caused by tensile stress present in coating and they also depend on the mechanical strength of the substrate (Pina, 1987). Figure 6 shows a fatigue fracture surface of a chromium coated specimen. Figure 6a shows all fracture surface and the fatigue crack initiation point (arrow in the figure). Figure 6b blows up this crack source shown in fig. 6a. Since the adhesion between chromium and substrate is strong, the cracks originated in the chromium plating act as stress concentrators in the interface and there is no difficulty in their propagation into the base material, despite the existence of a small compressive stress. Many times, these compressive stresses make the crack propagate at the interface before it penetrates the base material (arrow figure 6b). Therefore, the combination between high tensile stresses (by chromium and fatigue tests), and the stress concentrators caused by microcracks (Jones, 1989) and strong adhesion at the coating/substrate interface could explain the accentuated decrease in fatigue strength in AISI 4340 for both hardnesses. This behaviour was observed for all stress levels studied. In order to increase the compressive residual stress in the interface, which could make the crack propagation into the base material more difficult and thus improve the fatigue life, a shot peening treatment was applied before the chromium coating. The results are also shown in figures 4 and 5. Curves 4B and 5B show the residual stresses measured in specimen without chromium coating after the shot peening. Curves 4C and 5C show the stress profile developed in the specimens with pre-treatment of shot peening. Comparing curves 4B, 5B / 4C, 5C with curves 4A, 5A it could be observed that the influence of shot peening treatment occurred in an approximately 100μm depth for specimen with coating and in a 150μm depth for specimen without coating, for both hardnesses. Besides, the stresses in the substrate were larger in the specimen without coating as compared to specimen with coating (compare curves 4B, 5B to curves 4C, 5C). This factor may be due to the preparation process for surface plating which influences the affected layers by shot peening. Another possibility is the interaction between previous stresses at the substrate and the stresses induced by the electrodeposition process. Before making an analysis of the fatigue results reached by the shot peening treatment, it is necessary to know if the induced stresses are stable during the fatigue cycles.

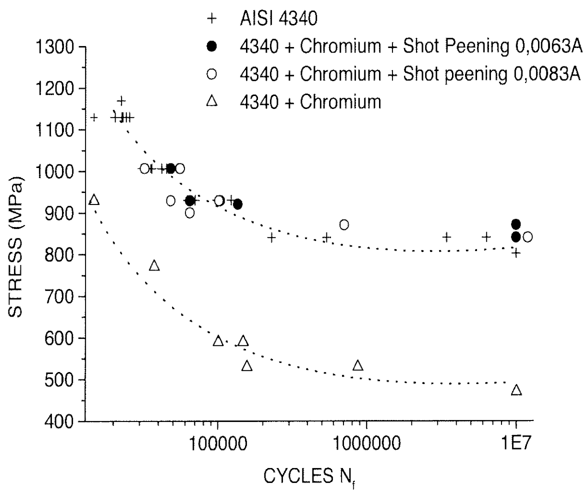

Figure 2 – Fatigue results of AISI 4340 with 53HRC.

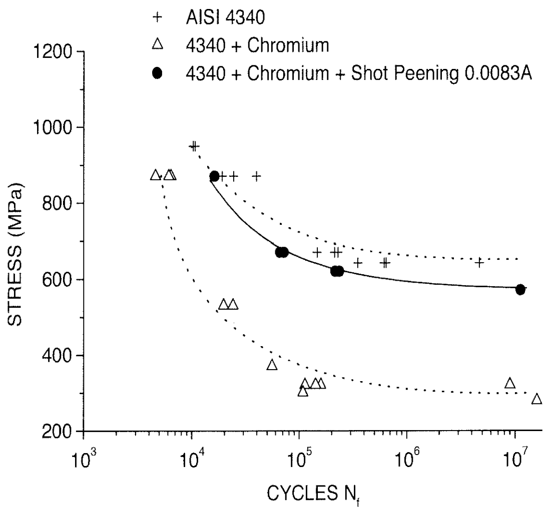

Figure 3 – Fatigue results of AISI 4340 with 39HRC.

Therefore the residual stress profiles were again measured in specimens submitted to 10^7 fatigue cycles, which established, with chromium plating, the fatigue limit in S/N curves. The results are seen in curves 4D and 5D. These curves when compared to curves 4C and 5C show a reduction in the induced compressive stresses by shot peening.

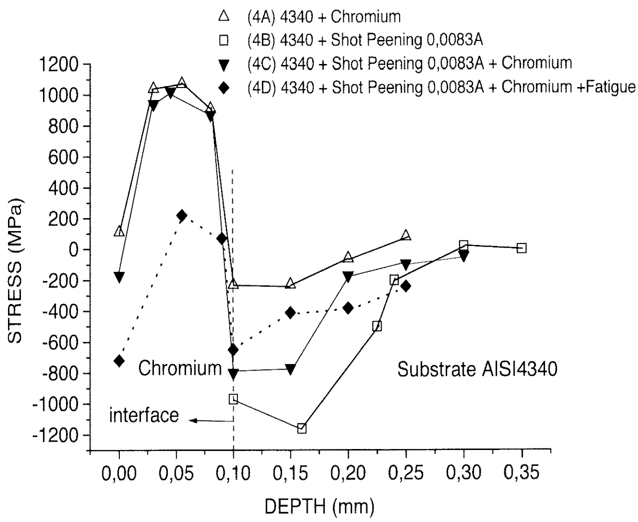

Figure 4 – Residual stress fields with 53HRC.

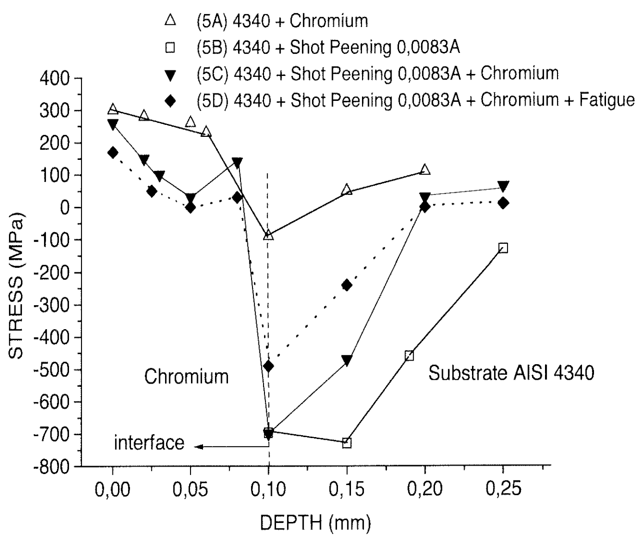

Figure 5 - Residual stress fields with 39HRC.

Nevertheless, the compressive stresses after fatigue are higher than the induced stresses by chromium electrodeposition (curves 4A e 5A). Back to figure 2 it can be observed that for both intensities the shot peening, as a pre-treatment, was able to restore the loss of fatigue strength caused by hard chromium plating. In figure 3 it can be noted that there was a significant recovery in fatigue resistance for 39HRC hardness due to shot peening. However, this recovery was not enough to restore all the loss caused by the chromium electrodeposition. A change in the shot peening parameters at 39HRC hardness could probably improve the results found here. Figure 7 shows a fatigue crack source in specimens under shot peening and covered with hard chromium, illustrating what happened to all the analyzed cases. In the specimens under shot peening the crack source took place at the substrate below the surface (arrow in fig. 7a and 7b). This fact demonstrates that the cracks from the coating are no longer the main cause of fatigue failure in shot peened specimens (compare fig. 7a and 7b to fig. 6b). It was shown in a previous work (Torres, 2002) that the shot peening process is more efficient in increasing fatigue strength when the CRSF is able to push the crack source beneath the surface at the base material.

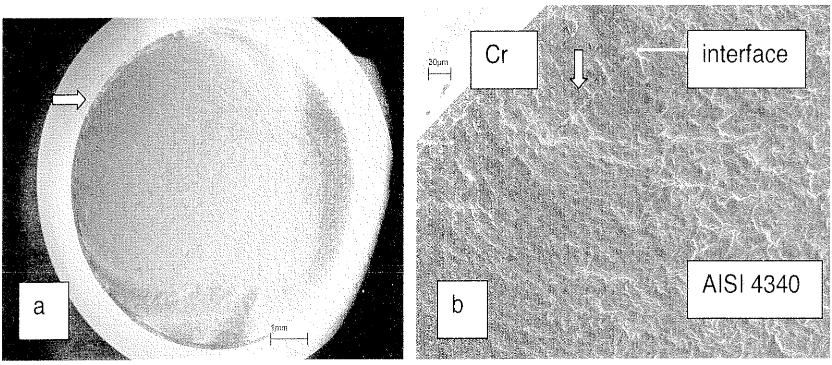

Figure 6 – a) An overview of the fatigue fracture surface: base material with chromium plating (53HRC); b) Detail of crack source.

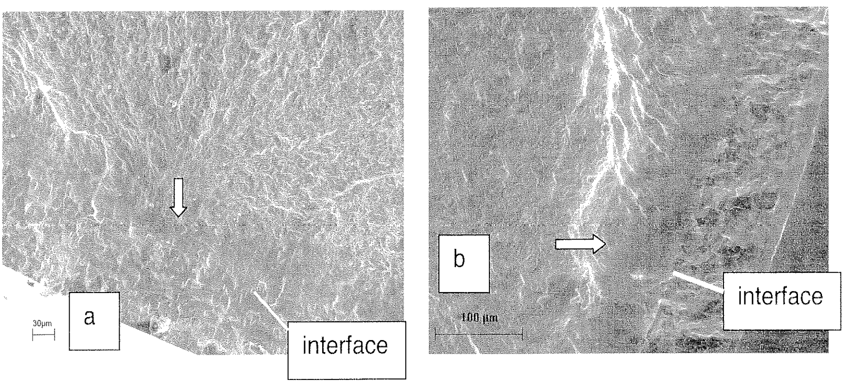

Figure 7 –Fatigue fracture surfaces: base material with shot peening and chromium plating a) 53HRC b) 39HRC.

This creates a larger crack nucleation period condition and, consequently, larger fatigue life in the components.

CONCLUSIONS

The usage of the shot peening process with intensities of 0.0063 and 0.0083A (suggested by Torres, 2002), as a pre-treatment to hard chromium electroplating is able to recover completely the loss of fatigue strength caused by this coating, in spite of the relaxation of the CRSF induced by shot peening, both for the electrodeposition and cyclic loading. The pre-treatment in 39HRC hardness was also efficient, although the recovery in fatigue strength was not total. In both hardnesses studied the shot peening made the crack source occur beneath the interface at the base material.

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