INFLUENCE OF ELECTROLESS NICKEL INTERLAYER THICKNESS ON FATIGUE STRENGTH OF CHROMIUM-PLATED AISI 4340 STEEL

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Abstract

Wear and corrosion resistance in steel components used in aeronautic industries are allowed by superficial treatment. Coatings systems to improve mechanical properties, generally, decrease components fatigue life due to microcracks, which propagate through the substrate. Electroplating chromium has as characteristic a high tensile residual stresses originated from the electroplating process. These residual stresses increase in accordance to electroplated layer growing and relaxation occurs due to microcracks formation during electroplating process. Microcracks density is related to high tensile residual stresses, hardness and corrosion resistance. Effective methods to promote high fatigue strength in chromium coated components have been developed. In this work, is intended to evaluate the intermediate electroless nickel layer thickness outcome on chromium electroplated AISI 4340 steel. S-N curves were obtained from rotating bending fatigue tests in two hardness levels and with three thickness of intermediate electroless nickel layer. Fracture analysis was made by using the scanning electron microscopy.

Introduction

Increase of wear, tear and corrosion resistance of many aeronautical components steel is obtained through a hard chromium superficial treatment.

Systems of superficial coatings, which improve these properties, reduce the fatigue life of these components drastically due to the coating cracks starting and penetrating through the substrate. The result of crack propagation in the substrate, implicates in a reduction of the useful life of a component.

Experiments with hard chrome electroplated high strength steels showed that despite of an increasing in wear, tear and corrosion resistance, a reduction of the fatigue strength, when compared with uncoated material, was observed - Sartwell *et al* [1], Hotta *et al* [2].

One of the characteristics of the chrome electroplating is to possess high tensile residual stresses, originating from of the electroplating process - Kuo and Wu [3], Horsewel [4]. Residual stresses increase according to the coating thickness layer growing and are softened by microcracks formation in the coating generated by the electroplating process. Basically the microcrack density is related with the high tensile residual stresses, the hardness and resistance to corrosion - Tyler [5], Lin *et al* [6]. Due to these characteristics, effective methods to increase the fatigue strength of the chromium-electroplated components are being studied.

Some authors like Doong *et al* [7], Chen and Duh [8] observed that the placement of Ni electroless interlayer in medium steel coated with TiN by PVD process increased adhesion, hardness and corrosion resistance.

Nascimento *et al* [9] studied the influence of an intermediate Ni electroless layer on the fatigue strength of AISI 4340 steel chromium electroplated and observed an increase when compared with the base material chromium electroplated.

Considering the fact that cracks initiation is a superficial phenomenon aspect such as residual stresses at surface, compressive residual stresses can increase fatigue life - Souza *et al* [10], Nascimento *et al* [11]. Results from the literature indicate that high velocity oxy fuel (HVOF) spraying has great potential as a coating process, as a consequence of interesting mechanical behavior offered by this thermal spraying technology - Torres and Voorwald [12], Pina *et al* [13], Wiklund *et al* [14].

In this study, the thickness influence of an intermediate Ni layer on the rotating bending fatigue strength in steel chromium electroplated, is evaluated. S-N curves were obtained for base material, base material chromium electroplated and with Ni interlayer between the base material and the coating. Scanning electron microscopy techniques (SEM) and optical microscopy were used to observe crack origin sites and the existence of a uniform coverage of nearly all substrate

Experimental procedures

Fatigue tests specimens were quenched from (815°C – 845°C) and tempered in the range of (520 °C ± 5 °C), for a period of two hours, to obtained hardness of 38-42 HRc. For the hardness of 49-53 HRc, a double tempering at 220 ºC, for a period of 4 hours each, was performed. Schematic representations of the heat treatments are indicated in Figs 1 and 2.

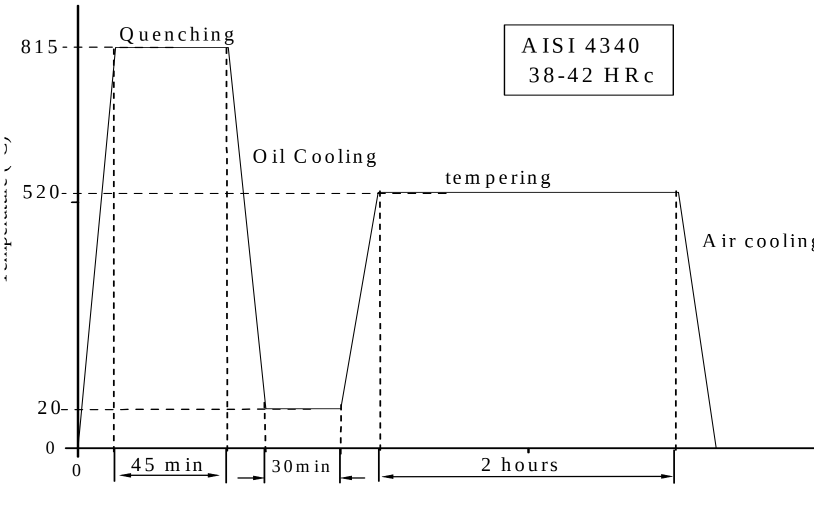


FIGURE 1. Schematic representation of heat treatments for hardness 39-42 HRc.

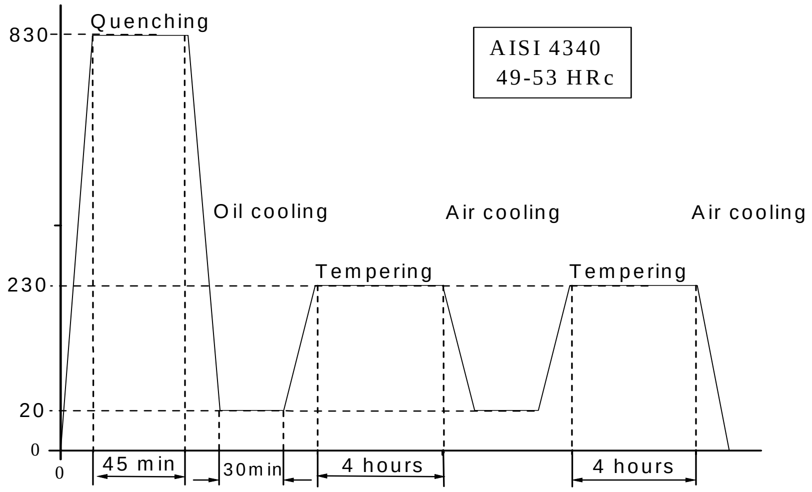


FIGURE 2. Schematic representation of heat treatments for hardness 49-53 HRc.

Chemical analysis of the material indicates accordance with specification. Specimens were prepared from bars with approximate diameter of 14.4 mm and length of 6 m, with hardness equal to 23 HRc. Samples were submitted to heat treatment, to reach hardness of 38-42 HRc and 49-53 HRc, respectively.

After final preparation, specimens were subjected to a stress relieving heat treatment at 190 ^{o}C for 4 hours to reduce residual stresses induced by machining. Rotating bending fatigue tests were conducted using a sinusoidal load of frequency 50 Hz and load ratio R= -1, at room temperature, considering as fatigue strength the complete specimens fracture or 10^{7} load cycles. Twelve groups of fatigue specimens were prepared to obtain S-N curves for rotating bending fatigue tests, as indicated in Fig. 3.

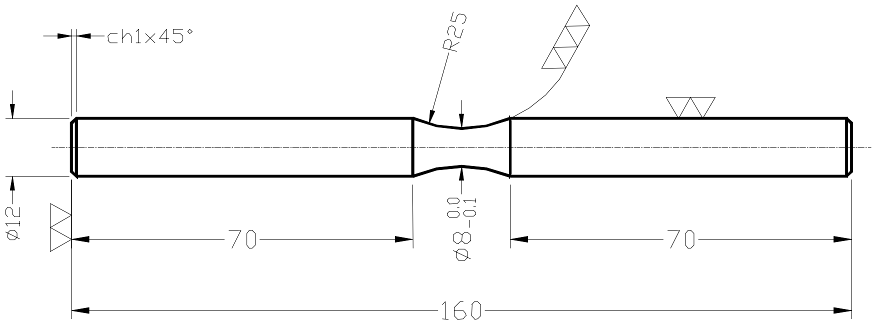


FIGURE 3. Rotating bending fatigue testing specimens

Specimens of base metal (steel AISI 4340, in the hardness of 39HRc and 52HRc);
Chromium electroplated specimens, 39 HRc-b and 52 HRc-b;
Specimens in the condition Bb, 39 Bb;
Specimens in the condition Bm, 39 Bm;
Specimens in the condition Ma, 39 Ma;
Specimens in the condition Mb, 52 Mb;
Specimens in the condition Mm, 39 Mm and 52 Mm;
Specimens in the condition Aa, 39 Aa and 52 Aa;
Specimens in the condition Ab, 39 Ab;
Specimens in the condition Am, 52 Am.

TABLE 1. Tests conditions.

	Adopted criterion	
	Thickness	Nomenclature
Deposit of nickel	7.5 μm________16.0 μm	B - low
	16.0 μm________30.0 μm	M - medium
	30.0 μm________53.0 μm	A - high
Deposit of chrome	120 μm________160 μm	b - low
	160 μm________250 μm	m - medium
	250 μm________300 μm	a - high

Hard Chromium Electroplating

The conventional hard chromium electroplating was carried out from a chromic acid solution with 250g/l of CrO_3 and 2.5 g/l of H_2SO_4 at 50 - 55 ºC, with a current density from 31 A/dm^2 to 46 A/dm^2, and speed of deposition equal to 25 μm/h. A bath with a single catalyst based on sulphate was used.

Electroplating of nickel

The electroless nickel deposition was performed in a solution containing 20 g/L of $NiSO_4$ and 24 g/L of NaH_2PO_2, 2ith pH 5, temperature 82 °C to 88 °C and speed deposition of 8 μm/h to 10 μm/h, resulting in coating with high phosphorus in around of 10-12%. Before superficial treatment applications the specimens were vapour degreased and alkaline degreased and desoxided in hydrochloric acid solution. After the electroplating, samples were treated a 19°C, for 23 hours to avoid hydrogen embrittlement.

Results and Discussion

Figure 4 shows S-N curves for base metal, in the hardness of 39 HRc and 52 HRc, and AISI 4340 steel chromium electroplated

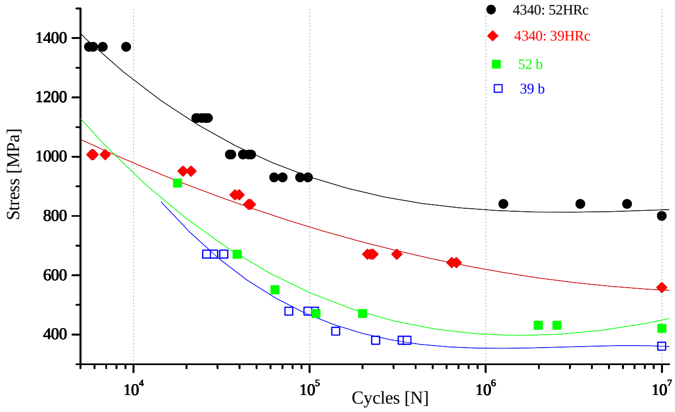


FIGURE 4. S-N curves for base metal, in the conditions of 39 HRc and 52 HRc, without and with hard chrome coating in low thickness (120 μm <b <160 μm).

Comparison of fatigue curves shown in Fig. 4, indicates the effect of hard chromium electroplating on the fatigue strength reduction of AISI 4340 steel, for hardness equal to 39 HRc and 52 HRc. High tensile residual stresses, microcracks density contained in the coating and strong adhesion coating/substrate interface which allow crack growth from the coating through the interface into the base metal are responsible for the decrease in fatigue strength.

For low cycle fatigue, in the condition of 39 HRc, predominance of plastic deformation inhibits the influence of the electroplated chromium layer. Around 10^5 cycles, a reduction in the fatigue strength in order of 30% and for fatigue limit in order of 35%, is observed.

Base metal with hardness equal to 52 HRc is negatively influenced by chromium coating in low and high cycle fatigue by an amount of 25% and 41%, respectively. Fatigue cracks starting from coating-substrate interface are represented in Fig. 5.

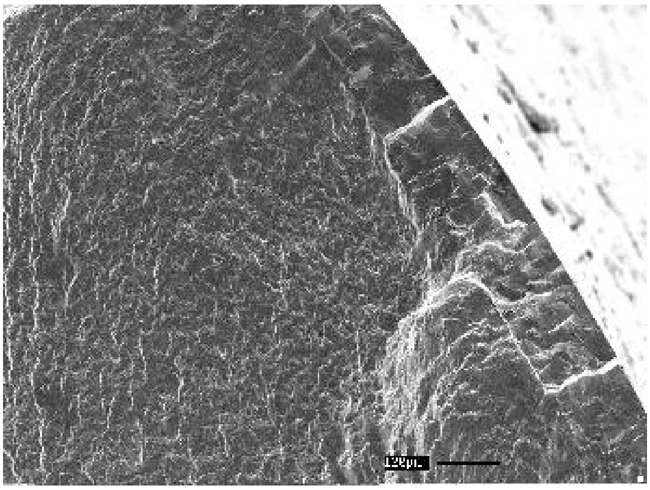


FIGURE. 5. Fracture surface from a bending fatigue specimen electroplated with hard chromium and fatigue tested

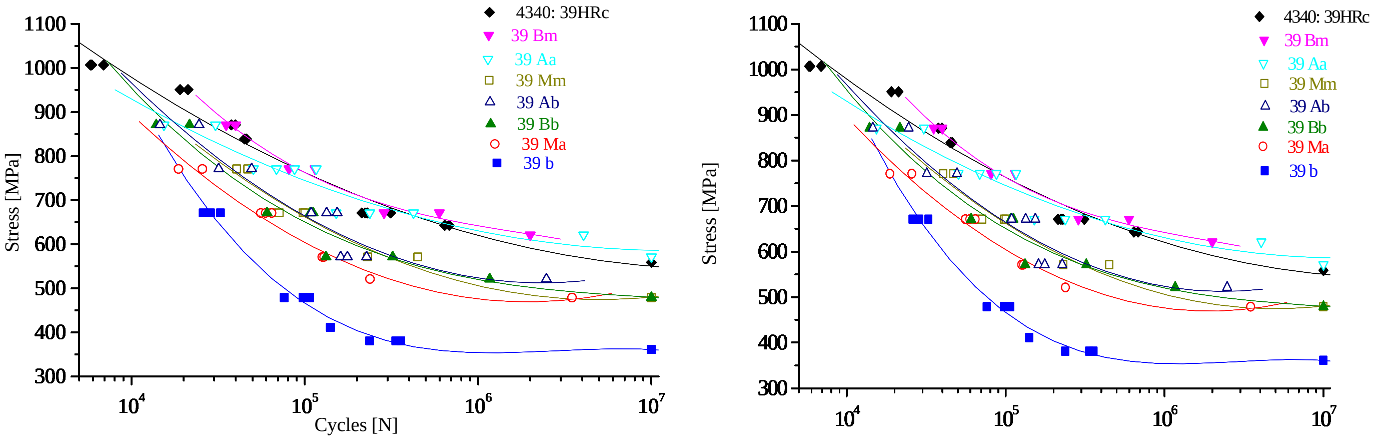
Nascimento *et al* [9], analyzed microcracks density in chromium plating and obtained 223 microcracks/ cm with a standard deviation of 57.5 microcracks/cm. Pina et al [13] showed that the microcracks density changes along the thickness of coating, being higher in the core and lower in the surface of the coating and in the substrate/coating interface.

Studies on effects of multilayers indicate differences in the mechanism of cracks propagation in relation to one layer coating [11,12]. An electroless nickel underlayer acts as barrier to crack propagation.

From literature, it is known that fatigue resistance is highly dependent on hardness and residual stresses on the surface and near to the substrate [13,14]. These properties can change during the testing as a function of the applied load. Hotta *et al* [2] observed that for stresses below 1180 MPa, residual stresses remains unchanged.

Figures 7a and 7b show rotating bending fatigue S-N curves for base material hard chromium electroplated and base material with intermediate nickel-plating layer and hard chromium electroplated, for 39 HRc and 52 HRc, respectively. It is indicated that fatigue strength was restored due to the presence of an intermediate electroless nickel layer, in comparison to base metal chromium electroplated.

For 39 HRc experimental results indicate, for low and high cycle fatigue, recovery in fatigue strength for curve Bm. Comparison between curves Ab and Ma indicates better results for low thickness of the intermediate nickel layer. Curves with low nickel thickness, Bm and Bb indicate that less recovery of fatigue strength in the case of low hard chromium electroplated thickness. For high chromium coating thickness, better fatigue results are obtained with high electroless nickel interlayer thickness.

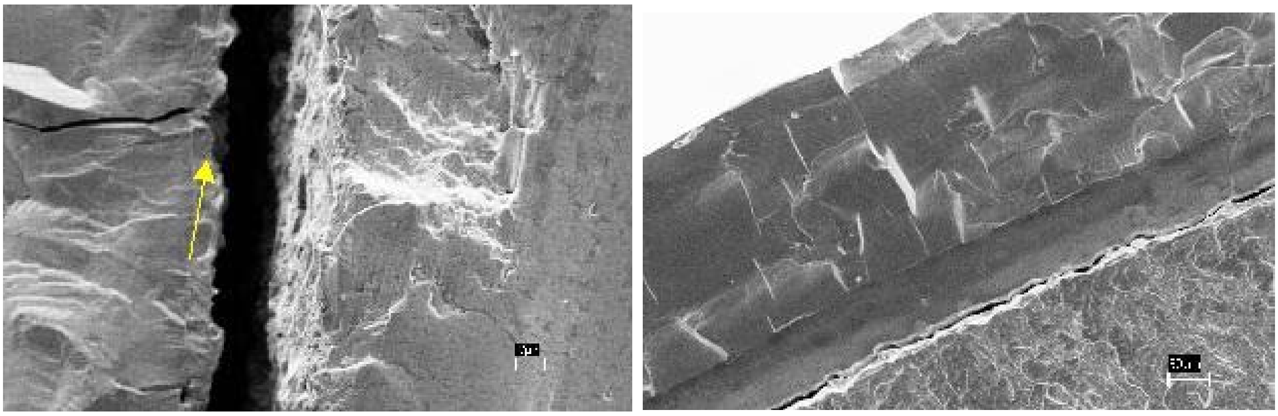


a) 39 HRc

b) 52 HRc

FIGURE 7. S-N curves for base metal chromium electroplated and with nickel interlayer..

Fracture surface analysis indicates in Figs 8a and 8b that electroless nickel interlayer act as a barrier to crack propagation.



a) curve 39 Bm

b)curve 52 Am

FIGURE 8. Fracture surface of specimen

Conclusions

1. Experimental results indicate a significant reduction in the fatigue strength of AISI 4340 steel associated with chromium electroplating.

2. S-N curves indicate the importance of the electroless nickel underlayer as a barrier to crack propagation.

3. For base material with hardness equal to 39 HRc, better fatigue results were obtained with electroless nickel interlayer in the range (7.5 μm – 16 μm) and hard chromium electroplated coating with thickness 160 μm – 250 μm.

4. For 52 HRc hardness materials, in low cycle fatigue, results were insignificantly dependent on coating thickness. In the case of high cycle fatigue (10^7 cycles), a better in material behavior was observed for 30 μm – 53 μm, independent on the hard chromium electroplated thickness.

5. Figure 7b indicates the rotating bending fatigue S-N curves for hardness equal to 52 HRc, it is clear that electroless nickel interlayer is responsible for an increase in the fatigue strength.

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