PLASMA THERMOCHEMICAL TREATMENTS ON CARBON STEELS

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Abstract. *Plasma thermochemical treatments have been employed to improve many tribological and mechanical properties, as well as the protection against corrosion. In this work plasma thermochemical surface treatments of nitriding, nitrocarburizing and nitrocarburizing plus post-oxidation have been done. The treatments were made on AISI 1010 mild steels. To investigate the influence of the process parameters on the mechanical properties and corrosion resistance, the samples were treated at three temperatures (673, 773 and 873 K), the time was varied from 10 to 60 min and three different gas concentrations were used. The structure and phase composition were characterized using scanning electron microscopy (SEM) and X-ray diffraction (XRD). The corrosion resistance was evaluated by salt-spray fog, electrochemical and mass loss in acidic solution tests. The samples were also characterized by micro hardness, fatigue and tensile test. The results revealed interesting features, for instance, the excellent corrosion resistance combined with high surface hardness (significantly higher than that obtained by salt-bath or gas nitriding).*

Keywords*: corrosion resistance; nitriding; microhardness; mechanical porperties; plasma processing*

1. INTRODUCTION

Plasma nitriding and nitrocarburizing are thermochemical treatments, which have been used to improve several chemical and physical properties of steels as corrosion and wear resistance, surface hardness and fatigue life [1-4]. For several years the major application of plasma nitriding was to increase the wear resistance of machine components. Recently, due to environmental aspects, the process has become cost-effective and, is now being applied to many structural components, where corrosion and fatigue resistance play an important role [5, 6].

For wear applications the treatment cycles are long, usually of several hours, in order to assure ticker compound and diffusion layers [7]. These long treatment cycles are indiscriminately used also to treat steels used in structural applications. However, as was shown elsewhere, short treatment times, bellow one hour, can be very effective to improve the corrosion resistance [8]. In this work we present results concerning the fatigue, tensile and flexure behavior of plasma nitrided, nitrocarburized and nitrocarburized plus post-oxidized AISI 1010 mild steel, conducted in short treatment cycles, under 1 h. Samples, treated at different temperatures, times, and gas concentrations, were investigated.

2. EXPERIMENTAL

Cleaned and degreased samples of AISI 1010 mild carbon steel sheets with 0.6 mm thickness were treated. No grid or polishing was applied to the sheet surfaces. Samples of AISI 1010 plain carbon steel, with 0.5 mm thickness, galvanized by hot-dip with a zinc layer of 150 g m-2 were also used in the mechanical tests. The plasma thermochemical treatments were performed with a pulsed d.c. glow discharge in an industrial furnace (Metal Plasma Ltd). Before the thermochemical treatments the samples were cleaned and heated up to the process temperature in a discharge containing H_2-50%Ar during 30 min. The other process parameters are given in table 1. For the flexure tests the treated sheets were cut in small pieces of 30 x 50 mm. The measurement of the applied load against the deformation was made in a three-point flexure machine, according the ASTM D-790 Standard. The samples used in the tensile and fatigue tests were machined according the ASTM E8 and ASTM E 466 Standards, respectively. The tensile tests were made in a EMIC DL 2000 machine. Three samples were used for each treatment parameter. The fatigue tests were carried out in a MTS hydraulic machine using a frequency of 25 Hz and a stress ratio of 0.2.

Table 1: Process parameters used in the plasma thermochemical treatments.

Process	Symbol	Temperature (K)	Time (min)	Gas flow ratio (%)			
				H_2	N_2	CH_4	O_2
Nitriding	N1	673	10	50	50	-	-
	N2	673	15	50	50	-	-
	N3	673	30	50	50	-	-
	N4	773	10	50	50	-	-
	N5	773	15	50	50	-	-
	N6	773	30	50	50	-	-
	N7	773	30	25	75	-	-
	N8	773	60	25	75	-	-
	N9	873	30	25	75	-	-
Nitrocarburizing	NC	873	30	13.5	85	1.5	-
Nitrocarburizing	NCO	873	30	13.5	85	1.5	-
plus post-oxidation		673	30	90	-	-	10

3. RESULTS AND DISCUSSION

3.1. Flexure tests

The curves of the applied load as a function of deformation obtained in the flexure tests of samples treated at different conditions are shown in figure 1. Regardless of great differences in the compound layer thickness and hardness, all treated samples have almost the same elasticity modulus, which is higher than that of the untreated steel.

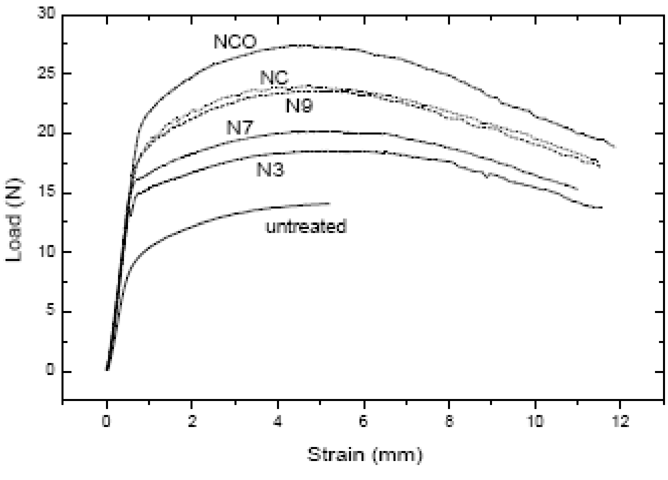

Figure 1: Load as a function of deformation in flexure tests.

However, an increase of the yield and flexural strength was observed for all treated samples. The behavior of the yield and flexural strength with the thickness of the compound layer is shown in figure 2. Both yield and flexural strength are shifted to higher stress with increasing layer thickness. There is a linear increase of the yield and flexural strengths with layer thickness for nitriding temperatures up to 773K. Although these strengths further increase for the treatments conducted at 873 K, just above the Fe-N eutectoid temperature, there is a reduction of the ratio between the yield and flexural strengths and the layer thickness, probably due to increase of grain size and other microstructural changes, that reduces the bulk hardness. A detailed microstructural characterization of the treated samples is shown elsewhere [8]. Thus, the improvements of the thicker and harder compound layer on the yield and flexural strengths are compensated by loss of hardness of the steel, resulting in the experimental curves shown in figure 2.

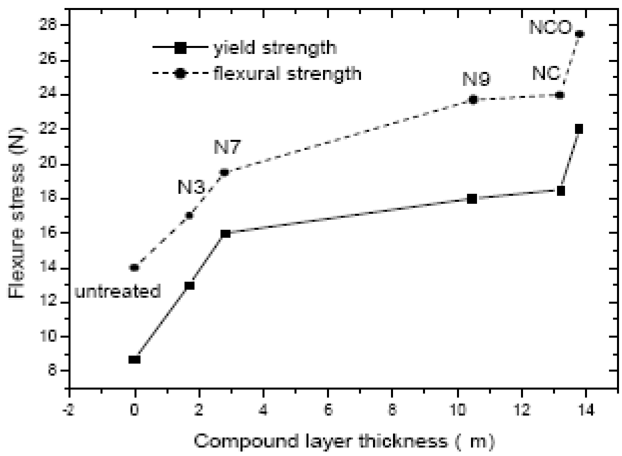

Figure 2: Yield and flexural strengths as a function of the compound layer thickness.

3.2. Tensile tests

The results of the tensile test are shown in figure 3. There is no change on the tensile properties of samples nitrided at 673 K, when compared with the untreated and galvanized samples. However, the values of yield and tensile strengths increase significantly for samples nitrided at 773 K, due to the increase of the compound layer thickness. Increasing the treatment temperature to 873 K leads to different features. The tensile strength further increase, whereas the yield strength stay at the same level observed for samples treated at 773 K.

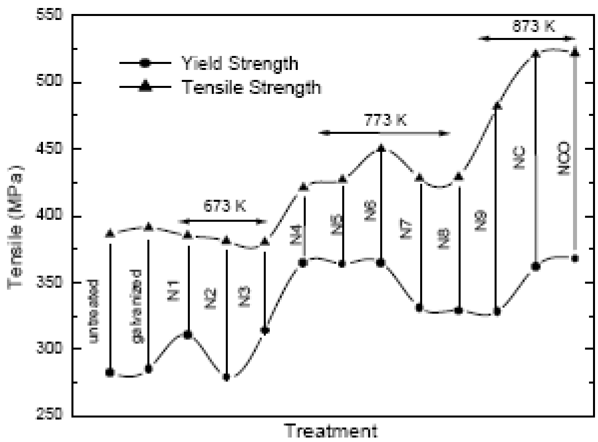

Figure 3: Yield and tensile strengths of samples with different treatments.

A plot of tensile strength as a function of the compound layer thickness is shown in figure 4. Its behavior is very similar to that observed for the flexural strength, i.e., there is a reduction of the ratio between the tensile strength and the layer thickness, when thetemperature increases from 773 K to 873 K, due to annealing effect.

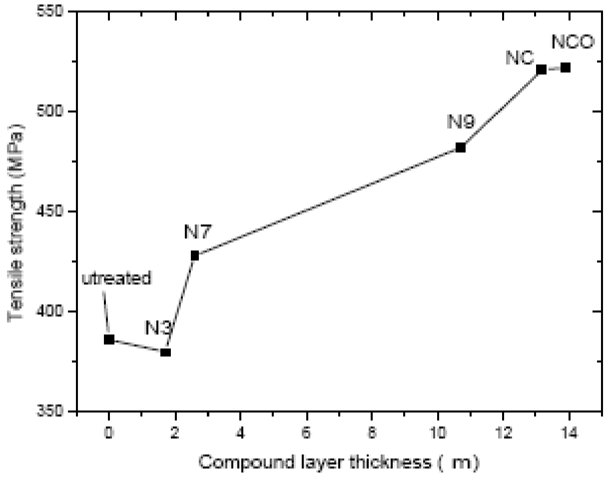

Figure 4: Tensile strength as a function of the compound layer thickness.

3.3. Fatigue tests

The compressive stress of the compound layer increases the stress required to cause crackinitiation in a given number of cycles. As a consequence, the fatigue life increases with increasing layer thickness and hardness. The curves of maximum stress in fatigue, as a function of the cycle number to failure of samples nitrided, nitrocarburized and nitrocarburized plus post-oxidized are shown in figure 5.

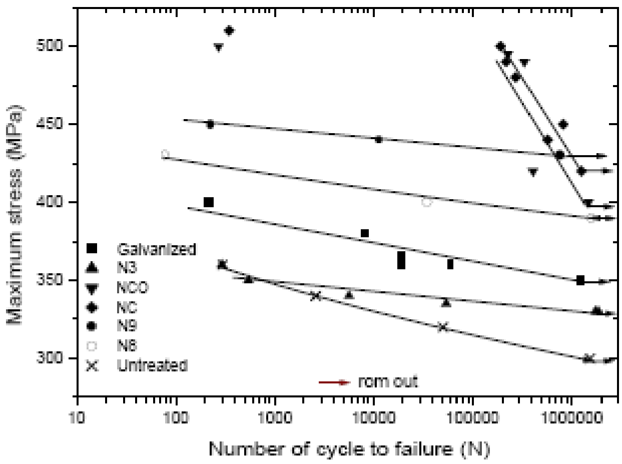

Figure 5: Maximum stress in fatigue as a function of the cycle number to failure.

There is an improvement in fatigue life of all treated samples. Even for samples treated at 673 K, which have very thin compound layers thickness, below 1 μm, an improvement in fatigue life was observed. The behavior of the S-N fatigue curves for the nitrided samples is similar, showing a gradual improvement in fatigue life with increasing thickness and hardness of the nitrided layer, a result the agree with previous works [9, 10]. However, the fatigue life performance of the nitrocarburized and nitrocarburized and post-oxidizes samples were superior. Fatigue cracks initiate only at higher

stress levels, close to tensile stress of 550 MPa, as shown in figure 5. This is a surprisingly behavior, because the hardness, thickness, microstructure and phase composition of the compound and diffusion layers of samples nitrided at 873 K are very similar to the ones of the nitrocarburized samples at the same temperature [8]. The fatigue limit (considering more than 106) obtained for several treatments is show in figure 6. There is an increase of the fatigue limit from 300 MPa, for the untreated sample, to 400 MPa for the nitrided and nitrocarburized samples.

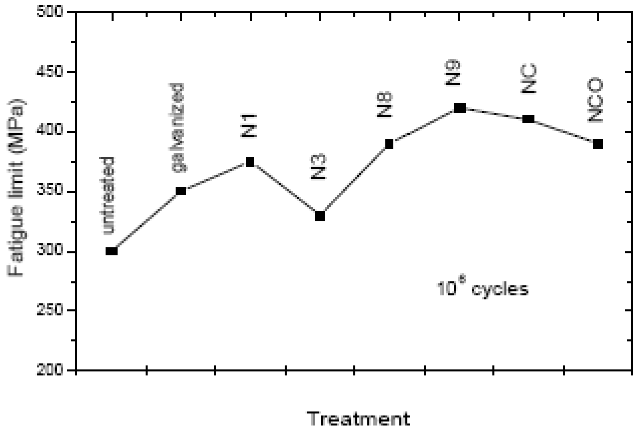

Figure 6: Fatigue limit of samples with different treatments.

4. CONCLUSIONS

The plasma thermochemical treatments of nitriding, nitrocarburizing, nitrocarburizing plus post-oxidation, conducted at short cycles, of AISI 1010 mild carbon steel sheets results in better performance concerning flexure, tensile and fatigue life. The results of these tests are summarized:

1 - The elasticity modulus of all treated samples is higher than that of the untreated steel, and seems to be invariant in the investigated range of process parameters. Both yield and flexural strength increase with increasing compound layer thickness. There is a linear increase of the yield and flexural strengths with layer thickness for nitriding temperatures up to 773K. The thicker and harder layers produced by treatments at 873 K are not effective to improve yield and flexural strengths, because, at this temperature, the hardness of the bulk material is reduced.

2 - The thickness of the compound layer plays an important role on the yield and tensile strength. A significant increase of yield and tensile strength was observed only for samples treated at 773 K, which shown layers with thickness higher than 3 μm. By increasing the temperature treatment to 873 K there is only a modest improvement of the tensile strength, due to the annealing effect.

3 - An improvement in fatigue life was observed for all treated samples. The behavior of the nitrided samples was similar, with a gradual improvement in fatigue life with increasing thickness and hardness of the compound layer. The samples nitrocarburized and nitrocarburized plus post-oxidized shown a superior performance.

5. ACKNOWLEDGEMENTS

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