INFLUENCE IN FATIGUE PROPERTIES DUE A PLASMA NITRIDING AND LASER CARBURIZING IN A BAINITIC STEEL

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ABSTRACT

The following work analyzed the changes in the properties of Fatigue in a 300 M aeronautical steel after the application of thermochemical treatments of plasma nitriding and laser carburizing. The microstructural characterization of the formed layers and the hardness obtained after the surface treatments were carried out. Thus, a comparison was made between the two treatments to verify which one has a better efficacy. It has been observed that the treatment of plasma nitriding improves significantly the fatigue properties of 300 M steel. It was also noted that laser carburizing was not efficient to improve fatigue life.

Keywords: *Surface treatment, 300M steel, Thermochemical treatment.*

INTRODUCTION

The steel used in this work has important aerospace applications such as in rocket motor envelope, aircraft landing gears and in general applications that require high mechanical properties, mainly structural (1). 300 M steel was developed as an improvement in ATSM 4340 steel, with an increase in silicon content to about 1.8%, to improve hardenability and the introduction of vanadium to reduce grain size. The ultimate strength of this steel varies from about 800 MPa for the annealed condition, to values around 2000 MPa for the quenched steel.
Surface treatments aim to improve properties such as resistance to corrosion and wear, but it is also important to assess whether these changes in the surface can influence mechanical properties (2). The surface treatments are important in many applications because can increase the surface hardness and the fatigue properties. There are several types of surface treatment, such as nitriding, carburizing, boration, surface quenching and others (2). These treatments increase the surface hardness, maintaining the ductile core, an interesting phenomenon for several applications, especially when there is contact between two machine parts. These treatments can also improve the fatigue performance (1).
This study became more importance when evaluating material used in structural elements of great responsibility, such as aircraft parts, missiles or rockets.

MATERIALS AND METHODS

Material and Treatment Used

The steel used in this work is 300M steel, its chemical composition is shown in Table 1, the chemical analysis was made by the Chemical Analysis Laboratory of the Materials Division of the IAE / DCTA, according to the ASTM-E-39-84 standards and ASTM-E-350-87. Before receiving the surface treatments, the steel underwent a heating treatment at 900ºC for 30 minutes, then it was cooled to 300ºC, where it remained for 2 h to form the bainitic structure, then it was cooled in air.

Table 1: Chemical composition of 300M steel (weight %)

Alloy elements	C	S	P	Si	Mn	Cr	Ni	Mo	Al	V	Cu
Weight %	0,39	0,0005	0,009	1,78	0,76	0,76	1,69	0,4	0,003	0.08	0,14

Fatigue Tests

The fatigue specimens were manufactured in according to ASTM E 466. The fatigue tests were conducted in a load of constant amplitude with a load ratio of 0.1 and a frequency of 20 Hz. The tests were carried out in a fatigue machine type MTS 810.23 M, with a load cell of 250 kN.

Microscopic Analysis

For the microstructural characterization the techniques of Optical Microscopy were used, going through the process of metallographic preparation (sanding and polishing) and chemical attacks with Nítal at 2%. The hardness of the layer and the hardened region was analyzed with microindentation hardness tests. The microindentations were performed in a Future-Tech FM 700 Microdurometer, belonging to the IEAv. For the measurements of hardness, a load of 50gf and an indentation time of 10s were used.

Surface Treatments

Plasma nitriding was carried out at 500ºC for 3 hours. This treatment was done in a reactor with a gas mixture with 75% N_2 and 25% H_2.
For laser carburizing an initial spray was made on the specimen with graphite and, later, the specimens were irradiated by laser to provide the formation of the hardened layer on the surface. For carburizing, a pulsed CO_2 laser was used, with a wavelength of 10.6 µm, output power of 125 W. The application was made, keeping the laser at maximum power, with a resolution of 500 dpi (dots per inch) and scanning speed, 600 mm/s. These parameters were based on previous work [5, 6, 7].

RESULTS AND DISCUSSION

The images in Figure 1.A show the microstructure of the 300 M steel as received, attacked with nital 2%. There are darker regions formed by perlite and lighter regions represent ferrite. To improve the mechanical properties of the steel, a quenching heat treatment with controlled cooling at 300 ºC was initially carried out, for the formation of the bainitic structure; this structure is shown in Figure 1.B. The hardness tests showed the hardness increased 300 HV of the ferritic/perlitic structure to about 500 HV for the bainitic structure, showing the effectiveness of the applied heat treatment. The increase is related to the type of microconstituent, as bainite is harder than ferrite or perlite.

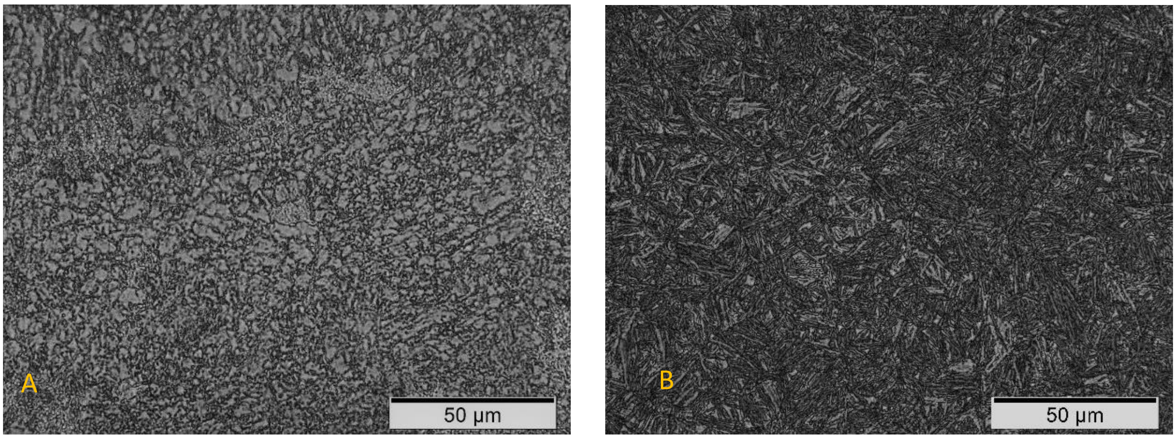


Figure 1: Showing the microstructure of the 300 M steel: (A) before the heat treatment (ferritic-pearlitic structure) and (B) after the isothermal treatment (bainitic).

After plasma nitriding, there was a significant increase in the surface hardness of the specimens, increasing the hardness to about 800 HV. Figure 2.A shows the image obtained by MO that allows the visualization of the nitriding layer. Figure 2.B shows the carburizing layer by the laser process, it does not have a hardness as high as the nitriding, but it has a greater thickness, its hardness reached a value around 600 HV.

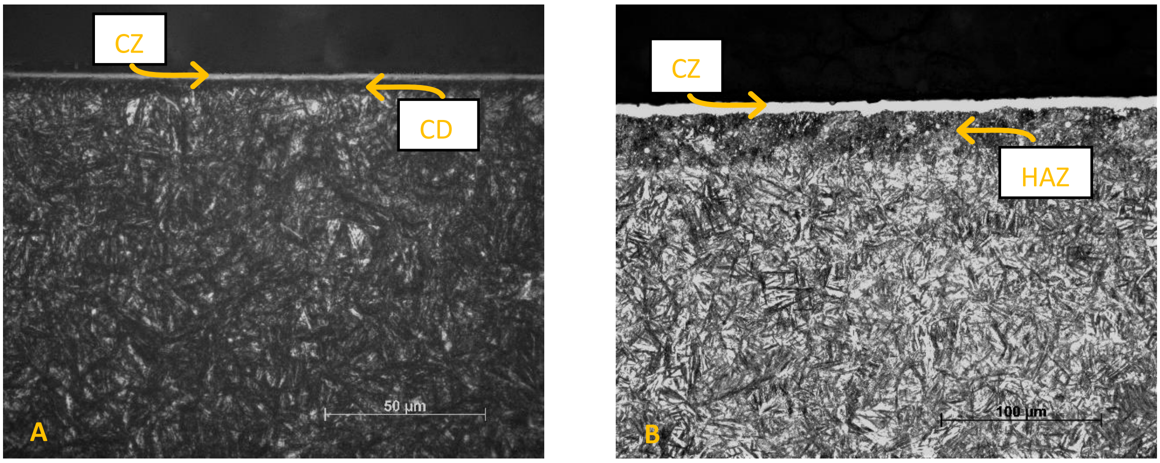
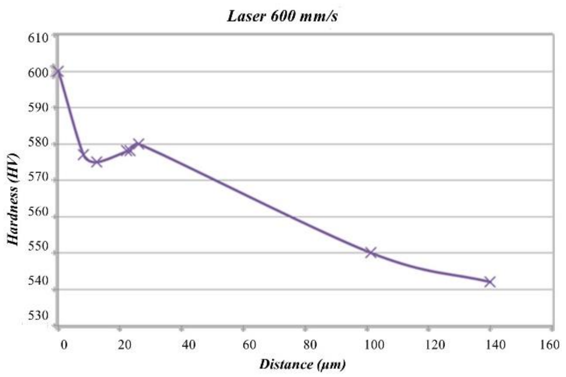


Figure 2: Microstructure of 300 M steel surface protection layers: (A) after plasma nitriding, (B) after laser carburizing.
CZ - Coated zone; DI - Atomic diffusion layer; HAZ - Heat affected zone.

The white layer of the nitriding steel has a white layer with approximately 3 µm (CZ - Coated Zone), below, the diffuse layer (CD) is observed, this zone is deeper, reaching about 60 µm. The white layer has a high nitrogen content and significantly increases the hardness observed in the region. In the diffuse layer, as it penetrates towards the interior of the material, the nitrogen content decreases, giving a decreasing gradient in the hardness value. These changes

in hardness are related to the formation of iron nitrides, which have a great influence on the mechanical properties of steel, are hard and fragile [(1)].
Due to the laser surface treatment applied, identified in Figure 2.B, it is noted that there was the formation of a white layer with a high concentration of carbon and iron, coated zone (CZ). Below this layer there is the region affected by the heat produced by the laser (HAZ, with about 60 µm), in which the occurrence of localized partial quenching is observed [(7)].
To assess the hardness of the treated surface and the region close to the surface, a hardness profile was performed on the surface, to show how the hardness varies until reaching the substrate hardness value. Figures 3.A and 3.B show the hardness profile for the two treatment conditions studied.
It is noted that the plasma nitriding has a less thick layer, but with a high hardness, superior to the hardness presented by the laser carburized treatment. The depth of the diffuse layer, formed due to plasma treatment, was also shown to be greater (about 60 µm), while the HAZ layer, formed by the laser process was more reduced, around 40 µm. This phenomenon occurs due to the high scanning speed of the laser used (600 mm/s), while in the plasma process the treatment is slower, as it depends on the nitrogen diffusion speed in the steel, the treatment time was 3 hours, at a temperature of 500 ºC.
In another study, were studied laser carbide at two different scanning speeds, observing only an increase in hardness for regions close to the surface in the process that used a laser speed of 800 mm/s. In this work, there is a more noticeable decreasing gradient of surface hardness towards the center of the sample, this effect is more accentuated due to the greater thickness of the sample, which facilitates the removal of heat and the rapid cooling of the same, favoring the formation of harder on steel [(6)].



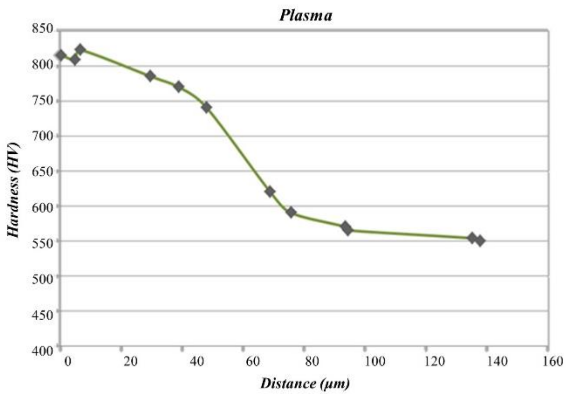


Figure 3: 300 M steel hardness profile: (A) after laser carburizing, (B) after plasma nitriding.

In this work, we analyzed how these treatments affect fatigue properties. The curves shown in Figures 4, 5 and 6 show how this property has been changed due to surface treatments.
Comparing the curves of bainitic steel without surface treatment with laser carbide, it is noted that there is a small loss in fatigue life for higher stress levels (between 1,000 and 1,200 MPa), however when analyzing the limit of fatigue, for 10^6 cycles, and life for lower stress levels, it is noted that the response of only bainitic steel was better. This reduction in fatigue life is mainly associated with the lower hardness observed on the surface, which, for this type of test, is quite relevant.

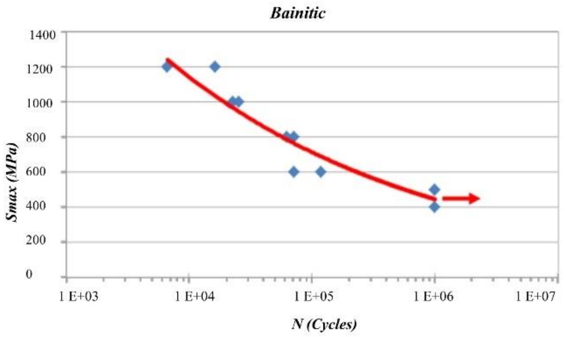


Figure 4: Fatigue S-N curve, for Steel 300 M without surface treatment.

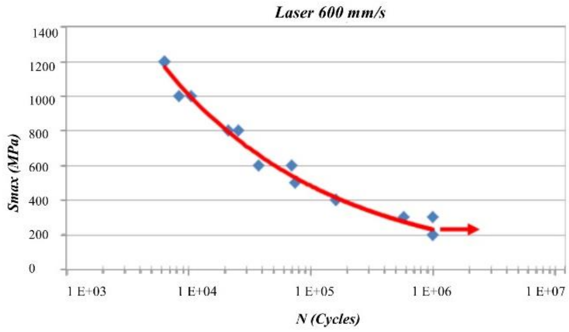


Figure 5: Fatigue S-N curve, for 300 M steel with laser carburizing treatment.

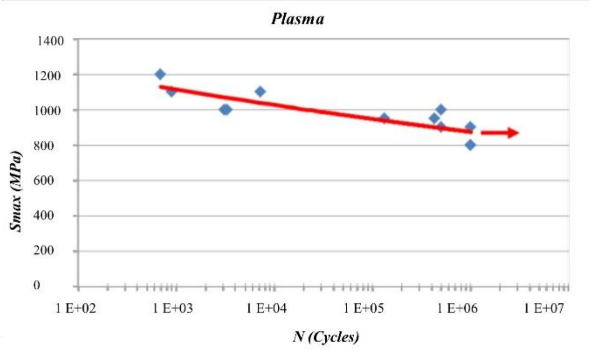


Figure 6: Fatigue S-N curve, for 300 M steel with plasma nitriding treatment.

When performing the same type of comparison, with the 300 M steel that was plasma nitriding, it is noted that the treatment provided a great increase in fatigue life, mainly for the lower stress levels. The fatigue limit, considered in this work for 10^6 cycles, was increased by about 200 MPa, of laser carburizing steel; for 400 MPa, for only bainitic steel; and to about 800 MPa, for plasma nitriding steel. This increase is very significant and allows a significant increase in fatigue life. This fact is associated with the high hardness of the produced nitriding layer and, it is known, that this treatment introduces compressive stresses on the surface and this effect is beneficial for fatigue life. This phenomenon delays the nucleation of the fatigue crack, increasing the component's life.

CONCLUSIONS

The heat treatment applied produced an increase in the hardness in the 300 M steel in the “as received” condition from about 300 HV to about 500 HV.
Plasma nitriding treatment formed nitride layers with high hardness, greater than 800 HV.
In the treatment of laser carburizing there was the formation of a white layer, with a high carbon content, but with a hardness slightly higher than that of the substrate, about 600 HV.
In the plasma nitriding treatment, the white layer formed was of high hardness, about 800 HV and it had a decreasing gradient until reaching the substrate hardness of about 60 µm.
There were changes in the fatigue tests. The laser treatment produced a reduction in the fatigue performance of 300 M steel and the nitriding treatment produced a beneficial effect, increasing significantly the performance of the steel in fatigue.

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