Macroparticles and mechanical properties of Titanium Thin Films Obtained with a Cathodic Arc and Magnetic Concentrator

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Abstract– *Ti films were obtained employing a cathodic arc with a straight magnetic filter. The films were characterized using, scanning electron microscopy,* profilometry , nanoindentation and a tribometer. *The films were found to be roughness and with* presence of macroparticles,. *The number of macroparticles, the film roughness and the deposition rate were also analyzed, The deposition rate depended on the axial position inside the duct,* the number of macroparticles decreases with increasing axial position, The friction coefficient and wear rate are diminished when the substrate was placed farther from the cathode, more inside the magnetic duct

Keywords-- Cathodic Arc , Magnetic Concentrator, macro-particles

I. Introduction

Thin film growth with cathodic arc devices has been widely investigated[1] due to this technique promotes the formation of dense, nano-structured films with good adhesion to the substrate and high deposition rate[2].

Cathodic arcs consist in a high current discharge running between two electrodes immersed in a vacuum chamber. In these devices a metallic plasma jet is ejected from the cathode surface. If a substrate is located facing the plasma jet its surface is coated with a metallic film. The main disadvantage of vacuum arc deposition is the emission of macro-particles (MPs) from the cathode. MPs in the coatings produce protuberances and depressions on the surface that not only increase the roughness, but also degrade mechanical properties[3]. Employing a magnetic field parallel to the propagation direction of the plasma jet, the ions are concentrated on this direction and the plasma density increases, thus the deposition rate increases and the fraction of MPs decreases[4]. Other studies show that increasing the frequency and width of the pulses decreases the number of macroparticles[5], A deposition of MPs to substrate were significantly decreased after 1 min of processing at bias[6], Applying short-pulsed bias leads to a 250-fold decrease in total macroparticle number[7].

In this work, Ti films were grown on stainless steel AISI 316 with a DC cathodic arc employing a magnetic concentrator. Substrates were placed facing the cathode at different distances respect to the entrance of the magnetic concentrator. Morphological and tribological features of the coatings were studied. The film surface was examined by SEM ,the uniformity of the films was studied with a profilometer. Hardness measurements were performed by a Nanovea nano-indenter and wear tests by a CSEM tribometer.

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II. EXPERIMENTAL SETUP AND PROCEDURE

The experiment was carried out in a d-c vacuum arc system, which is shown schematically in Figure 1.The discharge was produced between a cylindrical Ti cathode (60 mm in diameter) and a grounded annular Cu anode (80 mm in diameter). Both electrodes were mounted on an insulating piece that set an electrode separation of about 15 mm. The cathode was surrounded by a floating shield. The discharge circuit consisted in a current supply (18 kW, 150 A) in parallel with a capacitor bank (165 mF) connected to the electrodes through a series inductor (2.8 mH) in order to provide arc stability. A tungsten striker brought into contact with the cathode surface and later removed was employed to trigger the discharge. A stainless steel duct 25 cm long and 10 cm in diameter was connected electrically isolated behind the anode, As shown in figure 1.A magnetic field was established by an external coil wrapped around the stainless steel tube.

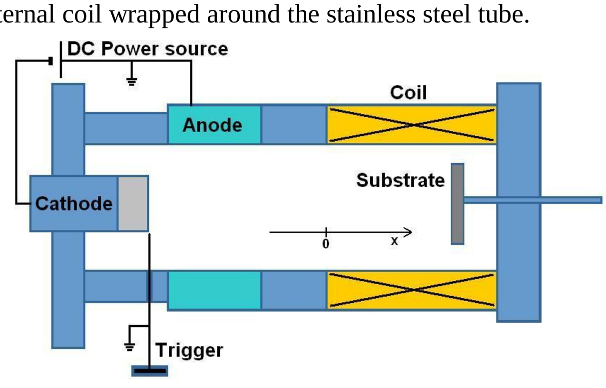

Fig1. Schematic diagram of the d-c vacuum arc system

The solenoid beginning was located at 20 cm from the cathode surface. The arc current was 120 A. The magnetic field in the

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center of the solenoid was 120 G. The vacuum system, composed of a mechanical and two diffusion pumps, kept the pressure chamber at 10-5 mbar.

The substrates were disks (19 mm in diameter and 2 mm in thickness) of stainless steel 316. They were placed at different axial distances from the cathode surface and mounted on a heater that holds the temperature at (210 ± 10) ºC. The exposure time to the discharge for growing the films was 150 s. The samples were weighted prior to and after the coating. From the measured deposited mass, the mean deposition rates were evaluated.

The film surface was characterized. The morphology was studied by scanning electron microscopy (SEM) with a Philips ElectroScan 2010 microscope and a profilometer XP-2 High Performance Surface Profiler , the tribological properties with a The CSEM Pin-On Disk - Tribometer and the hardness with a Nanovea nanoindenter with IBIS Technology.

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III. RESULTS

The characterization of the magnetic field, in the interior and along the filter, gives a profile with the maximum value in the center of the filter, 120G, and decreases towards the ends up to 60G. The result is shown in Figure 2.

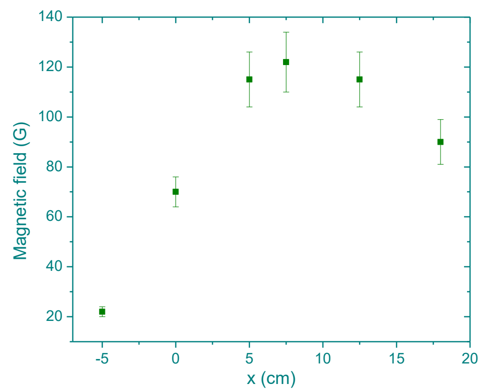

Fig 2. Magnetic field profile along the filter axis

The rate of deposition, inside the magnetic concentrator , is maximum where the maximum magnetic field and decreases towards the ends of the duct, as shown in Figure 3.

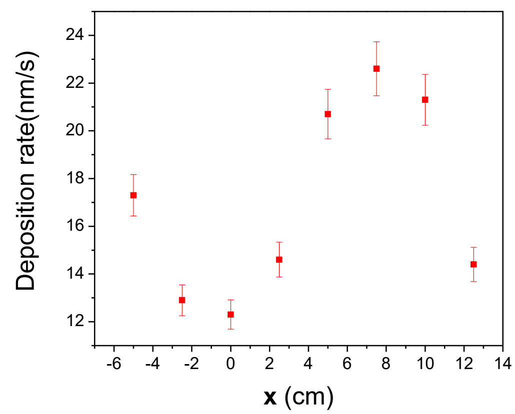

Fig 3. Deposition rate as function of the axial position inside the magnetic concentrator

The films of titanium grown at different positions, have macro-particles with height higher than 2 μm, along a diameter d, at different x positions, -5cm,0,+5cm and 7.5cm, the signals were obtained with a profilometer and shown in Figure 4.

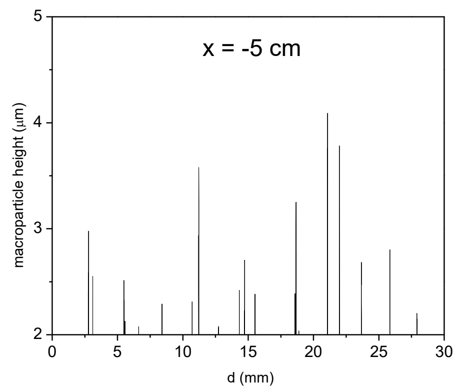

Fig 4a Macroparticles with height higher than 2 μm at x=-5cm

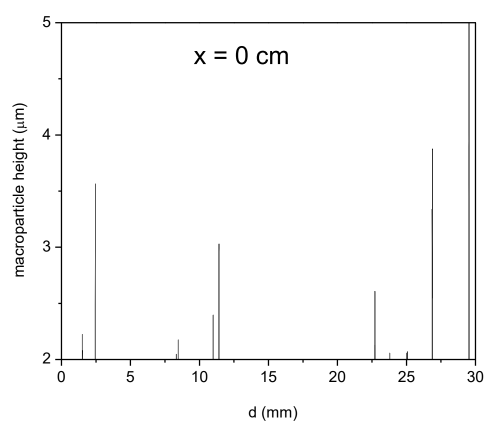

Fig 4b. Macroparticles with height higher than 2 μm at x=0 cm

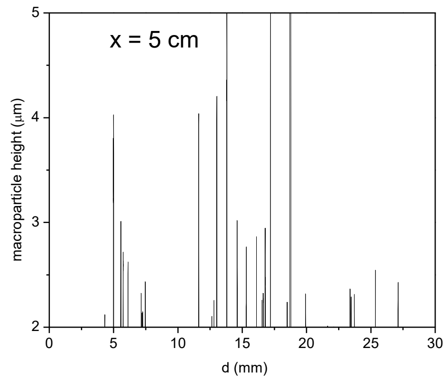

Fig 4c Macroparticles with height higher than 2 µm at x=+5 cm

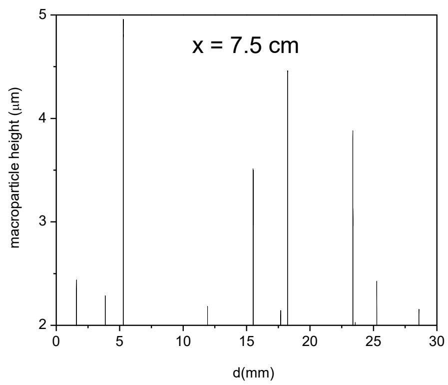

Fig. 4d Macroparticles with height higher than 2 µm at x=+7.5 cm

MECHANICAL PROPERTIES

The Wear was measured by the Ball-on-disc test using a 100Cr6 steel ball and 1N load, the results show that for the center positions where the field is maximum is less the wear, as shown in Figure 5.

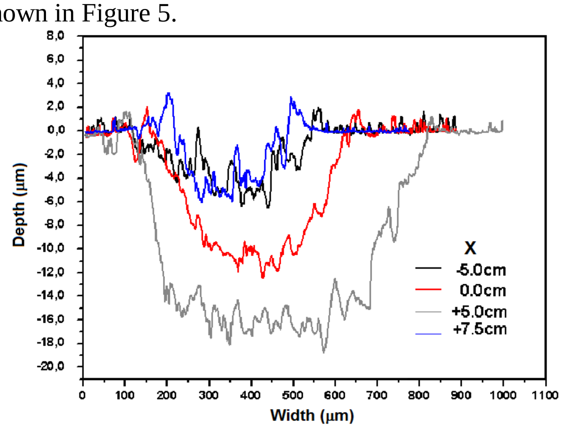

Fig 5. Profile of the wear track obtained after the Ball-on-disc test.

The friction coefficient decreased as the cathode-sample distance increased, as shown in figure 6, This fact can be attributed to a lesser number and size of MPs on the coating.

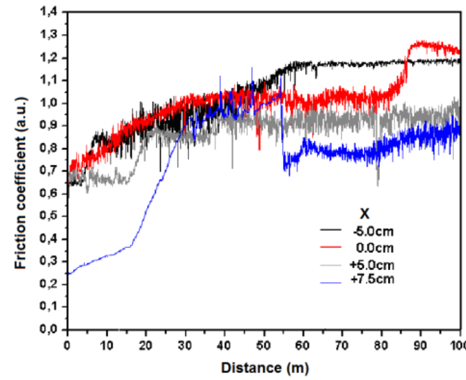

Fig 6. Relative friction coefficient as function of sliding distance in the ball-on-disc test

The hardness and elastic modulus are higher where the field is maximum. The following table summarizes the values of the mechanical properties

Tabla 1 values of the mechanical properties

Sample	x (cm)	Hardness H (GPa)	Elastic mod. E (GPa)	Wear rate (mm^3/Nm)	Friction coefficient
a	-5	7.6	149	$-3\cdot10^{-7}$	1.00
b	0	8.2	133	$-8\cdot10^{-7}$	0.97
c	5	5.2	138	$-2\cdot10^{-6}$	0.83
d	7.5	8.7	162	$-3\cdot10^{-7}$	0.72

MORPHOLOGY - SEM IMAGES

When the substrates were placed farther from the cathode surface, the MPs size and number diminished, so decreasing the surface roughness, the figure 7 show the images

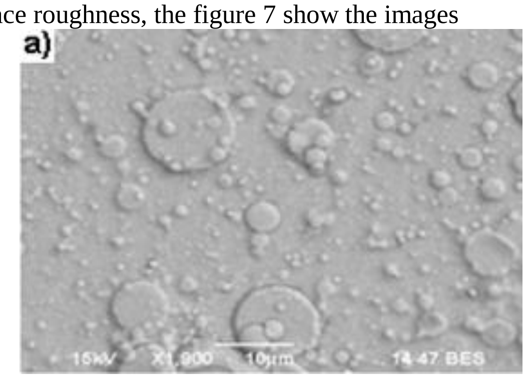

Fig 7a. Distribution of macro-particles at x=-5cm

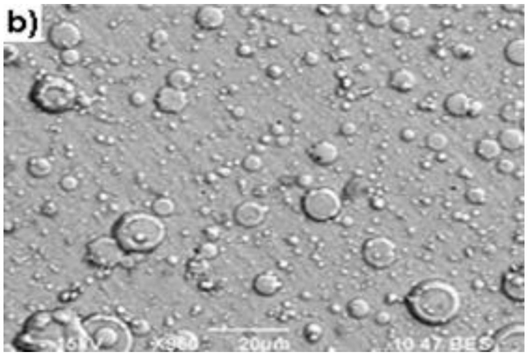

Fig 7b. Distribution of macro-particles at x=0cm

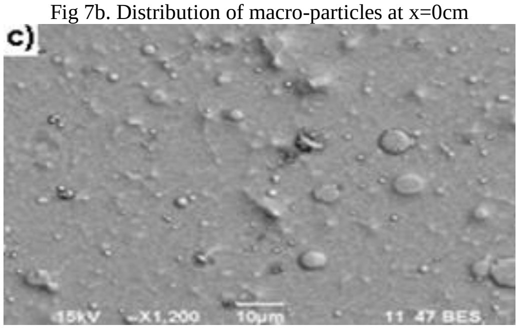

Fig. 7c. Distribution of macro-particles at x=+5cm

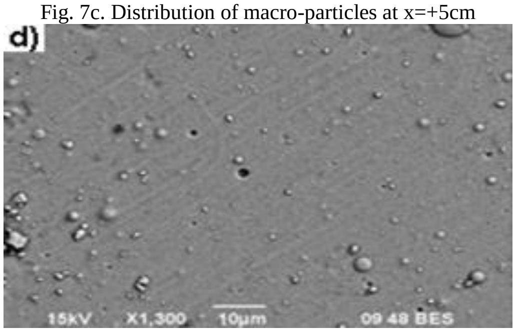

Fig. 7d. Distribution of macro-particles at x=+7.5cm

IV. CONCLUSIONS

The performed studies demonstrated that the position of the samples strongly influences on the homogeneity of the surface and the number of existing MPs on the coatings

The friction coefficient diminished -due to a decreasing of the surface roughness- when the substrate was placed farther from the cathode, more inside the magnetic duct

Best mechanical, morphological and tribological properties, such as highest hardness, lowest friction coefficient and lower wear rate, were obtained at the position where the magnetic field was maximum.

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