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Article

Tribological and microstructural analysis of multilayer ceramic films on D2 and 440 steels

Análisis tribológico y microestructural de películas cerámicas multicapa sobre aceros D2 y 440

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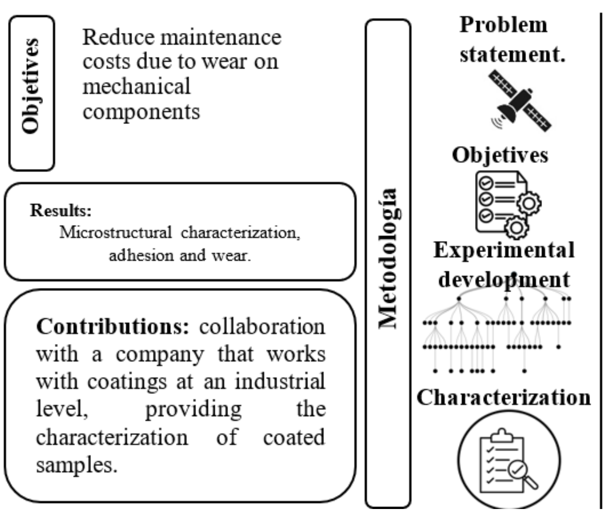
Abstract

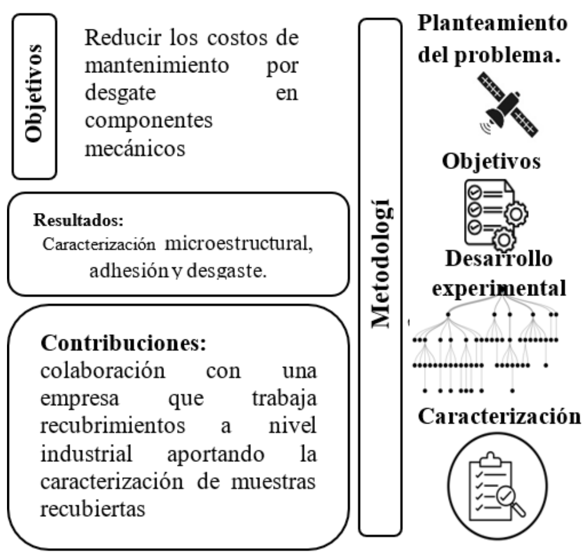
The objective of this work is to carry out the microstructural and tribological characterization of D2 and 440 steel substrates, coated with films whose architecture is TiAlN and AlTiN respectively, the samples that were characterized are obtained from the collaboration with the company SADOSA S.A. de C.V., who work coatings at an industrial level. The methodology that was used is divided into two aspects, within the microstructural characterization section, the samples were subjected to various microscopic analysis techniques (MEB) to observe the surface and by means of energy disperse spectroscopy (EDS) to corroborate the presence of the elements. in the film, through the use of calotest the thickness of the film was obtained and through optical profilometry to determine the surface topography. In the tribological characterization section, wear studies were carried out such as bolt on disc, obtaining information on the wear coefficient and by using the VDI 3198 standard, information on its adhesion was obtained.



Tribology, cathodic arc, AlTiN/TiAlN

Resumen

El objetivo de este trabajo es llevar a cabo la caracterización microestructural y tribológica de sustratos de acero D2 y 440, recubiertos con películas cuya arquitectura es TiAlN y AlTiN respectivamente, las muestras caracterizadas fueron obtenidas de la colaboración con la empresa SADOSA S.A de C.V, quienes trabajan los recubrimientos a nivel industrial. La metodología que se empleó se divide en dos vertientes, dentro del apartado de la caracterización microestructural las muestras fueron sometidas a diversas técnicas de análisis microscópico (MEB) para observar la superficie y mediante espectroscopia de energía dispersa (EDS) corroborar la presencia de los elementos en las películas, mediante el uso de calotest se obtuvieron los espesores de las películas y perfilómetria óptica para conocer la topografía superficial inicial. En el apartado de caracterización tribológica se llevaron a cabo estudios de desgaste tales como, perno sobre disco obteniendo información del coeficiente de desgaste y mediante la utilización de la norma VDI 3198 se obtuvo información sobre su adhesión.



Tribología, arco catódico, AlTiN/TiAlN

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Introduction

Materials science and tribology are interdisciplinary fields of study that together play a crucial role in industrial role in industrial and human development. Tribology is the science that studies phenomena such as friction, wear and lubrication. This science was created based on the need to reduce wear and analyze material losses in terms of mass, energy and efficiency, generated in the environment in which they operate [I].

The properties of materials can also be complemented by modifying their surface. These deposits can be applied using advanced methods such as chemical vapor deposition (CVD) and physical vapor deposition (PVD) to add properties to the surface of materials seeking to extend their useful life and reduce wear losses. This is achieved by depositing thin layers of other materials with beneficial properties with respect to the demand of the product [II-III].

Figure 1 shows a diagram of the main characteristics of the object of study of surface engineering, which are of utmost relevance due to their influence on the performance of the materials [IV].

Box 1

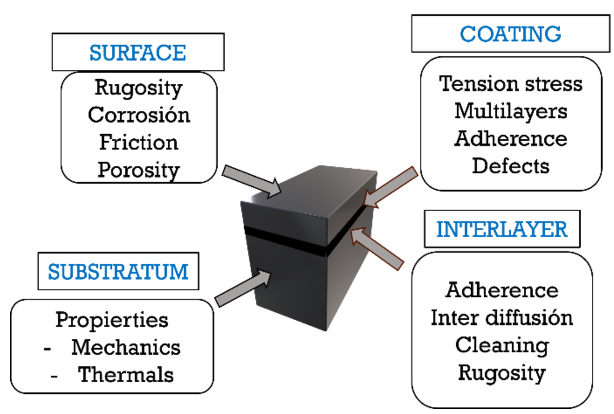

Figure 1
Coated substrate element diagram
Source: Own elaboration.

Ceramic coatings have been widely used in various engineering systems, protecting materials from harsh environments by their excellent wear and corrosion resistance properties while improving efficiency in energy storage and conversion [V-VI].

Within the PVD processes we find the cathodic arc deposition variant which is carried out within high vacuum chambers in which reactive gas (nitrogen) and working gas (argon) are injected, which generates the magnetic field in a plasma state through which the atoms travel from the target to the substrate, the target will be attacked by means of an electric arc, sublimating the material and detaching it, allowing it to be deposited on the substrate [VII-VIII].

Figure 2 shows a diagram of the PVD deposition process in the cathodic arc variant [IX].

Box 2

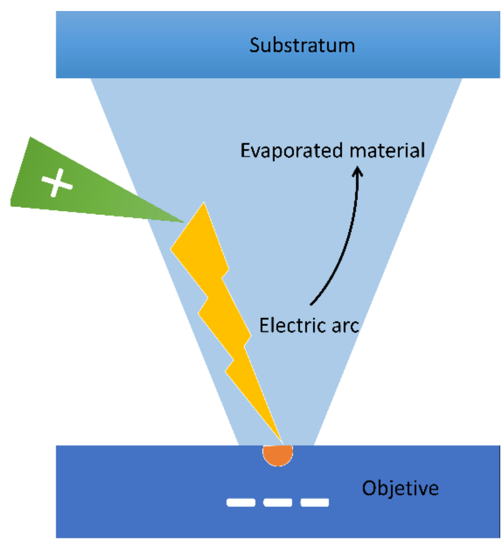

Figure 2
Catodic arc.
Source: Own elaboration.

Methodology

In the present work, TiAlN and AlTiN film deposits were developed using the physical vapor deposition (PVD) method in its cathodic arc variant; the process was carried out in a high vacuum reactor at the company SADOSA SA of CV., under conditions selected by requirements observed in the market demand, on D2 and 440 steel substrates. The deposited films were characterized microstructurally by the scanning electron microscopy (SEM) technique plus a qualitative and semi-quantitative analysis with energy dispersed spectroscopy (EDS), wear tests were also performed using a pin on a disk, and adhesion was evaluated by Rockwell C under the VDI3198 standard, the layer thickness was obtained using the calotest technique, topography by optical profilometry and the present phases and the preferential planes by XRD.

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Results

Using scanning electron microscopy figures 3 and 4, micrographs of the surface of the substrates were obtained in which we can observe conglomerations of material and porosities.

Box 3

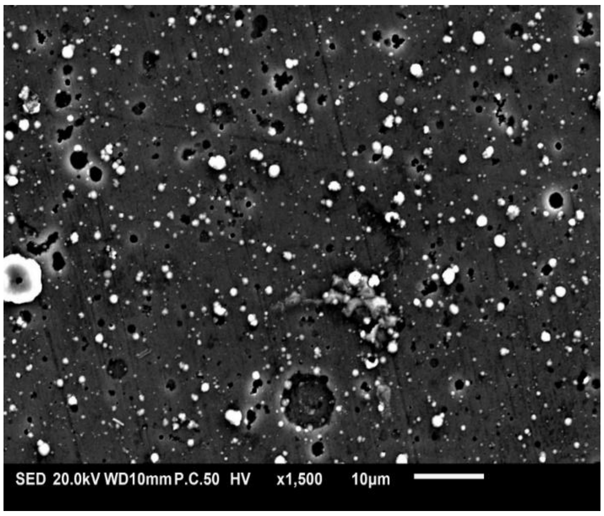

Figure 3
Micrography MEB substrate 440/AlTiN.
Source: Own elaboration.

Box 4

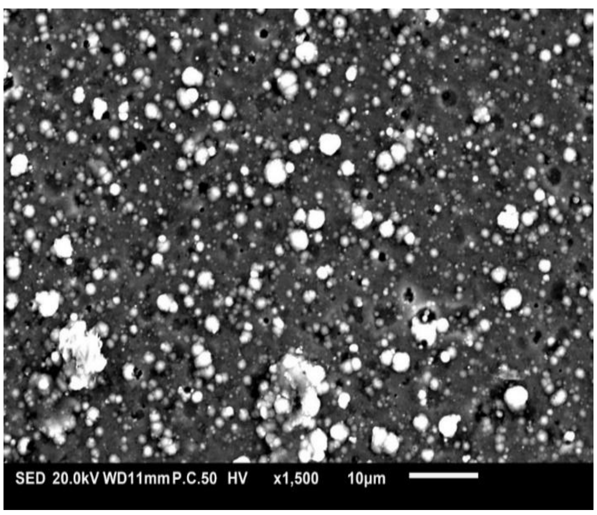

Figure 4
Micrography MEB substrate D2/TiAlN.
Source: Own elaboration.

The characterization of the analysis by energy dispersed spectroscopy, figures 5 and 6, obtained the peaks corresponding to the elements that make up the Al, Ti, N films deposited on the D2 and 440 steel substrates.

Box 5

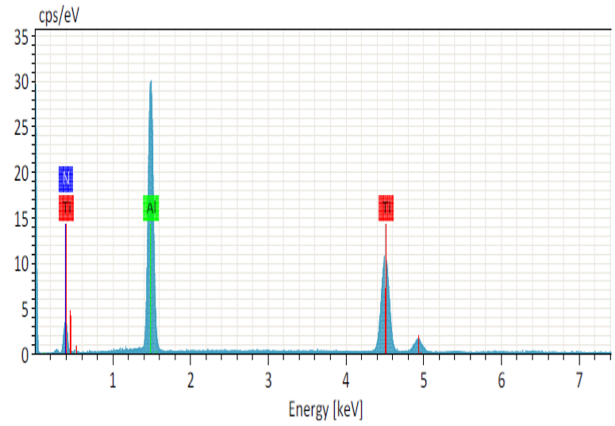

Figure 5
EDS coatings 440/AlTiN.
Source: Own elaboration.

Box 6

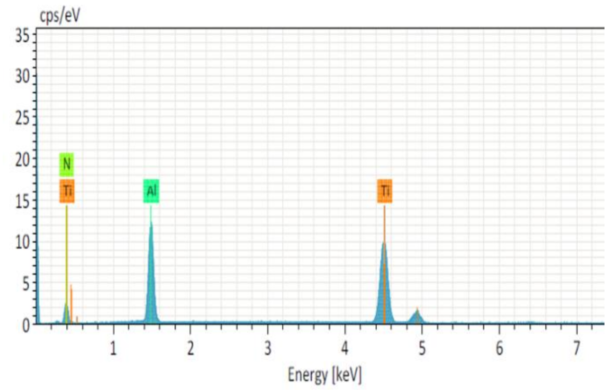

Figure 6
EDS coatings D2/TiAlN.
Fuente: elaboracion propia.

Table 1 shows the information obtained by SEM analysis of the percentages of material presents in the coatings obtained at 1500x.

Box 7
Table 1
Percentage of elements present

	%N	%Al	%Ti
TiAlN	21.53	25.21	53.26
AlTiN	24.27	39.59	36.14

The information obtained from the optical profilometry technique in figures 7 and 8, allows us to argue that the surfaces are homogeneous with uniform valleys and ridges are observed in both samples.

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Box 8

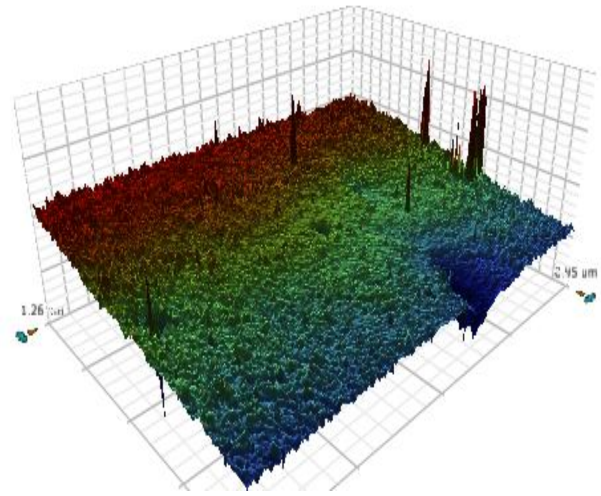


Figure 7

Optical sample profilometry 440/AlTiN.

Source: Own elaboration.

Box 9

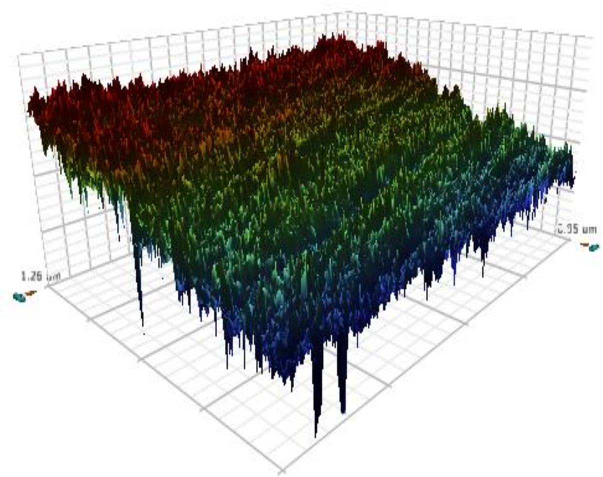


Figure 8

Optical sample profilometry D2/TiAlN

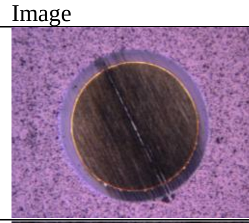
Source: Own elaboration.

The layer thickness was obtained using the CALOTEST method (table 2), finding a coating thickness of 2.54 microns for the coating on 440 steel, which has a bilayer structure where we find an adhesion layer with a thickness of 0.39 microns and a thickness of 2.15 for the coating composed of AlTiN; in the case of the TiAlN film on D2 steel, it has a thickness of 2.70 microns.

Box 10

Table 2

CALOTEST results both samples

Material	Image	Thickness
440 AlTiN		film 1 - 0.39 micrometers film 2 - 2.15 micrometers Total thickness: 2.54 micrometers
D2 TiAlN		film 1 – 2.70 micrometers Total thickness: 2.70 micrometers

XRD diffraction characterizations allowed observing the phases present in the synthesized coating and the substrate. In figures 9 and 10, TiAlN was found at approximately 45°, in additions to the substrate characteristics at 42°.

Box 11

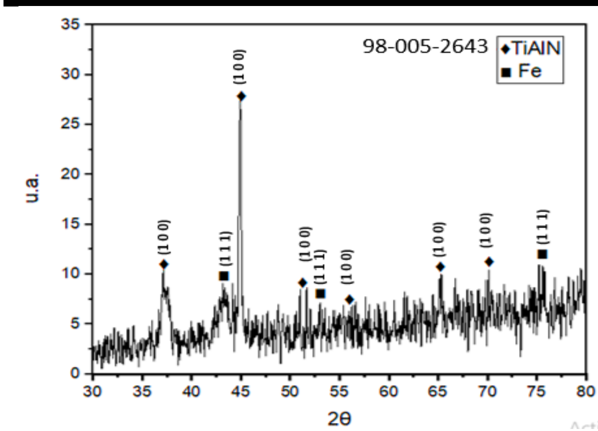


Figure 9

Coating diffractogram 440/AlTiN

Source: Own elaboration.

Box 12

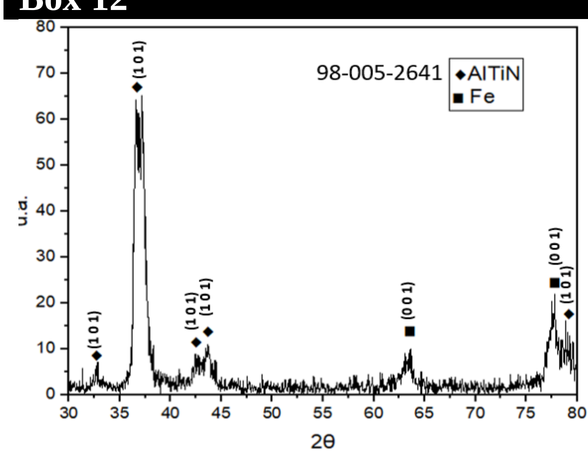


Figure 10

Coating diffractogram D2/TiAlN

Source: Own elaboration.

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Regarding the wear tests using a pin on a disc figure 11, the wear coefficient corresponding to each of the coated substrates was obtained. This test was carried out with the following parameters: 5 newtons of load, 250 meters of test, 0.15 m/s of speed and 5 mm diameter alumina sphere.

Box 13

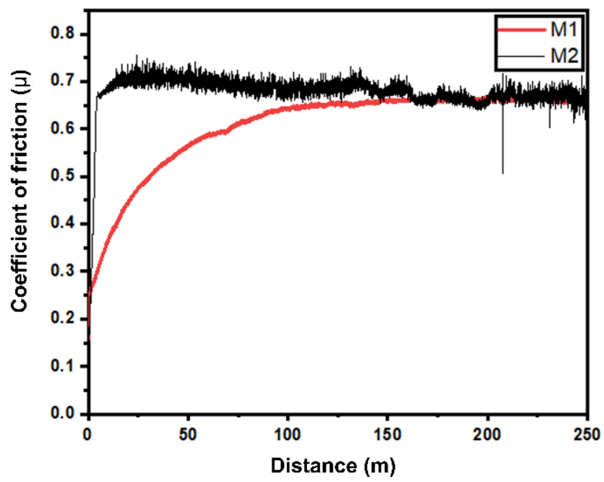

Figure 11

Graph of wear coefficient in both subtracts.

Source: Own elaboration.

Acknowledgements

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Conclusions

The results of the microstructural characterization and wear analysis techniques indicate that: the coatings have acceptable adhesion to the substrate according to the VDI 3198 test. A thickness of 2.54 microns was obtained for M1 and 2.70 microns for M2 respectively. Optical profilometry showed homogeneity on the surface of the analyzed substrates.

SEM revealed that the film surface is porous and uniform, while EDS analysis identified the presence of Al, Ti an N. XRD confirmed the presence of the AlTiN and TiAlN phases. Regarding the coefficient of friction, a more stable behavior is observed in the sample with AlTiN coating, and similar damage for both samples.

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Authors contributions

AVALOS ROA A. A.: writing, methodology, research, development, characterization, analysis of results.

MELO MÁXIMO L.: review and editing, consulting, validation, methodology, conceptualization.

MELO MÁXIMO D. V.: advice, validation, conceptualization, characterization.

VEGA MORÓN R. C.: advice, validation, conceptualization, characterization.

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This research was conducted without funding.

Abbreviations

MEB	Scanning electron microscope
XRD	X-ray diffraction
EDS	Energy dispersive spectroscopy
PVD	Physical Vapor Deposition
CVD	Chemical Vapor Deposition
TiAlN	Titanium/aluminum nitride
AlTiN	Aluminum/titanium nitride

References

Background

Hutchings, I., & Shipway, P. (2017). Tribology | ScienceDirect*: friction and wear of engineering materials*. Butterworth-Heinemann ISBM 978-0-08-100910-9.

Jemat, A., Ghazali, M. J., Razali, M., & Otsuka, Y. (2015). Surface Modifications and Their Effects on Titanium Dental Implants *BioMed research international*, *2015*(1), 791725 https://doi.org/10.1155/2015/791725.

Support

Pujari, S. P., Scheres, L., Marcelis, A. T., & Zuilhof, H. (2014). Covalent Surface Modification of Oxide Surfaces - Pujari - 2014 - Angewandte Chemie International Edition - Wiley Online Library, *53*(25), 6322-6356 https://doi.org/10.1002/anie.201306709.

Ding, C., Zhu, A., & Tian, Y. (2014). Functional Surface Engineering of C-Dots for Fluorescent Biosensing and in Vivo Bioimaging | Accounts of Chemical Research, *47*(1), 20-30 https://doi.org/10.1021/ar400023s.

McEntire, B. J., Bal, B. S., Rahaman, M. N., Chevalier, J., & Pezzotti, G. (2015). Ceramics and ceramic coatings in orthopaedics - ScienceDirect *Society*, *35*(16), 4327-4369 https://doi.org/10.1016/j.jeurceramsoc.2015.07.034.

Differences

Wang, Y. X., & Zhang, S. (2014). Toward hard yet tough ceramic coatings - ScienceDirect. *Surface and Coatings Technology*, *258*, 1-16 URL: DOI: https://doi.org/10.1016/j.surfcoat.2014.07.007.

Baptista, A., Silva, F., Porteiro, J., Míguez, J., & Pinto, G. (2018). URL: Sputtering Physical Vapour Deposition (PVD) Coatings: A Critical Review on Process Improvement and Market Trend Demands, *8*(11), 402
DOI: https://doi.org/10.3390/coatings8110402.

Inspektor, A., & Salvador, P. A. (2014). Architecture of PVD coatings for metalcutting applications: A review - ScienceDirect: A review. *Surface and Coatings Technology*, *257*, 138-153 https://doi.org/10.1016/j.surfcoat.2014.08.068.

Anders, A. (2014). URL: A review comparing cathodic arcs and high-power impulse magnetron sputtering (HiPIMS) - ScienceDirect. *Surface and Coatings Technology*, *257*, 308-325
DOI: https://doi.org/10.1016/j.surfcoat.2014.08.043.