Influence of alumina and titanium dioxide coatings on abrasive wear resistance of AISI 1045 steel

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Abstract: This project aims to compare the behaviour of an AISI 1045 steel´s abrasive wear resistance when is covered with aluminium oxide (Al_2O_3) or Titanium dioxide (TiO_2), of nanometric size, using the technique of thermal hot spray, which allows to directly project the suspension particles on the used substrate. The tests are performed based on the ASTM G65-04 standard (Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Apparatus). The results show that the amount of, lost material increases linearly with the travelled distance; also determined that the thermal treatment of hardening-tempering and the alumina and titanium dioxide coatings decrease in average a 12.9, 39.6 and 29.3% respectively the volume of released material during abrasive wear test.

1. Introduction

The surface of a component is susceptible to mechanical (friction and wear), chemicals, electrical, optical and thermal interactions. As a result in any design process should be considered the quality and the protection of the surface of a component; a possible method to protect it, consists of applying coatings, which can be metallic, polymeric and ceramic. Ceramic coatings are widely used because they can transform a substrate surface making it chemically inert, abrasion resistant, low-friction and easy to clean. The project seeks to determine how are affected the mechanical properties of wear resistance on a standard AISI 1045 steel, when it is thermally treated with a hardening-tempering process or is coated with particles of nanometric size of Al_2O_3 or TiO_2, through a process of thermal hot spray.

2. Conceptual framework

2.1. Materials nanostructured

Ultrafine microstructures with an average phase or grain size on the order of nanometers ($1nm=10^{-9}m$) are classified as nanostructured materials [1]. Currently, in a broader sense of the term, any material containing grains or clusters below 100 nm, or layers or strands of that dimension, can be considered nanostructured [2]. The interest in these materials has been stimulated by the fact that, due to the small size of the particles, grains, or phases, and the high ratio of volume-surface is expected that these can prove unique mechanical properties [3]. In nanophase materials, a variety of size-related effects can be incorporated by controlling sizes of constituent elements [4]. One of the most critical features of nanoparticles is a very high relationship surface-volume, with a large proportion of surface atoms. The large specific surface area provides exceptional properties for industrial applications [5].

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2.2. Coatings
A coating is a layer of a material that is applied to the surface of an object, called the substrate, which is usually of other material. The purpose of the coating is the improvement of the surface properties of the substrate: appearance, adhesion, corrosion, dissolution, wear or scratch resistance (hardness), among others. The coatings with improved properties are very demanded in various industrial sectors, either to optimize the characteristics of the structural elements to protect or create functionalized surfaces [1,6].

2.3. Thermal spray by flame
The thermal spraying by conventional flame was the first process of thermal spray developed and is still in common use. Processes by flame use chemical energy of the combustion gases to generate heat, being the oxy-acetylene torches the most common. These systems use one gun for projection of gases containing materials used for the coating and in some designs; additional air flow restricts the flame. The restriction of the flame affects expanding gases, creating in this way an area of combustion with very high temperatures. The nozzles also give shape to the pattern of the flame [7].

3. Methodology

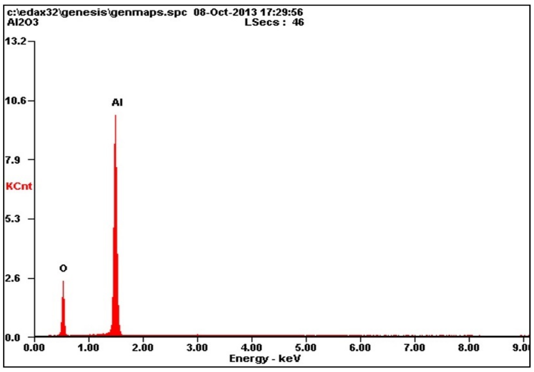
3.1. Morphological and chemical characterization of Al_2O_3 and TiO_2
Morphological and chemical characterization of Al_2O_3 and TiO_2, was performed through the technique of Scanning Electron Microscope; for which was used a microscopy equipment FEI brand QUANTA FEG 650 model. The images obtained from microscope allow to identify the shape and calculate the size of the particles that compose the material. Additionally, the microscope has integrated a system of Energy Dispersive X-ray Spectroscopy (EDS).

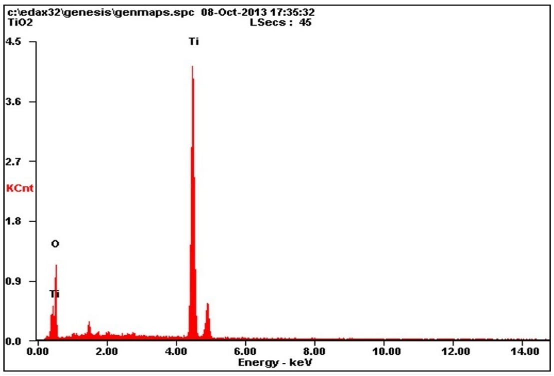
3.2. Deposit and characterization of alumina and titanium dioxide coatings
The coatings of Al_2O_3 and TiO_2 of nanometric size were carried out through the process of thermal spraying by flame, using an Eutalloy gun 85BX, which is adapted to a conventional gas burning equipment. The distance used between the torch and the base material was approximately 30cm, with an inclination from the horizontal of 60° [7]. The oxygen pressure used was 25psi and acetylene was 5psi, which defines a pressure relation of 1:5.

3.3. Testing
The tests were conducted in three different types of specimens: the first were produced in AISI 1045 standard steel; the second were of the same steel, but thermally treated with a process of hardening (warming 850°C and cooling in water) and tempering (warming 350°C and cooling with air); and the last were AISI 1045 steel with Al_2O_3 and TiO_2 coating of nanometric size, deposited through thermal spray by flame process. The tests are performed based on the ASTM G65-04 standard (Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus) [8].

4. Results

4.1. Morphological and chemical characterization of Al_2O_3 and TiO_2
Based on images obtained, of each of the materials used as coating, is analysed a pre-sample of the dimensions of the smaller side of 10 different particles, and with them is defined a sample size of 48 data to achieve a reliability of 95% and a maximum error of 5%. The average of the particle size of Al_2O_3 was 92.9nm; while the TiO_2 was 36.7nm. The chemical analysis of the powders used was carried out through the values of microanalysis by EDS, which are listed in Figure 1. The error percentage obtained between the calculated theoretical and the experimental atomic weight retrieved by analysis EDS, for Alumina and titanium dioxide was 3.3% and 9% respectively.



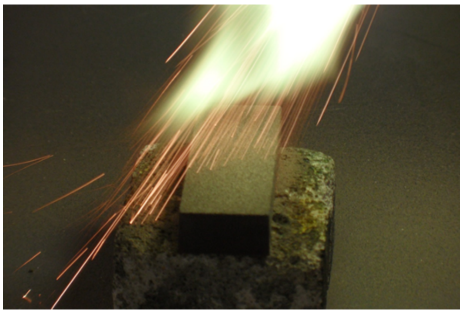


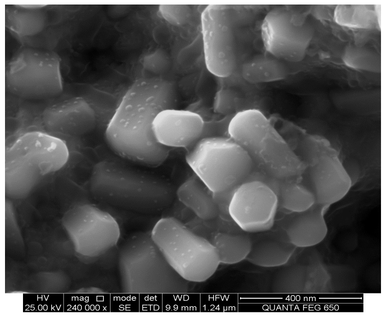
(a) (b)

Figure 1. Spectrum obtained in EDS analysis. (a) Alumina powder; (b) titanium dioxide powder.

4.2. Deposit and characterization of alumina and titanium dioxide coatings

The coatings obtained through the process of thermal spray by flame, Figure 2(a), over the specimens of AISI 1045 steel, can be seen in Figure 2(b); it can be concluded that coatings are uniform on the surface. Also can be said that the nanometric size materials used in deposits is preserved during the process, however, there is a tendency to agglomerate to form larger structures.





(a) (b)

Figure 2. Coatings deposition. (a) Process of thermal spray by flame; (b) coating of TiO_2.

4.3. Test results of abrasive wear resistance

Abrasive wear resistance tests result in a straight mark on the specimen, and therefore a removal of material. The results are listed in Figure 3.

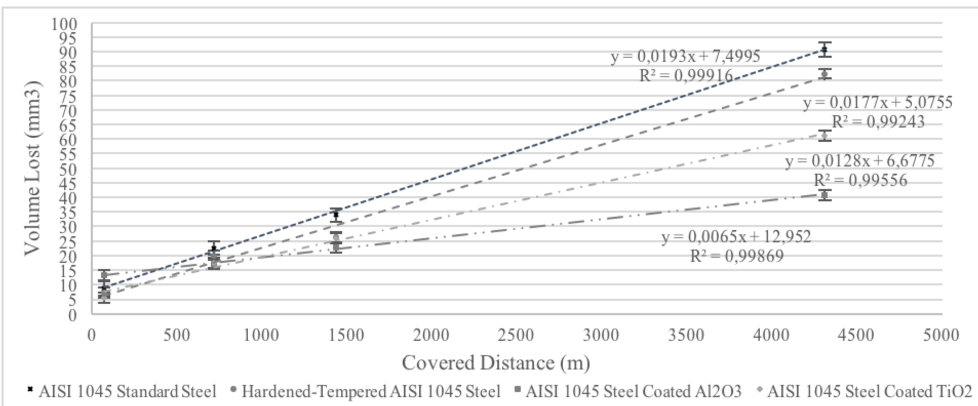


Figure 3. Comparison of the abrasive wear resistance in specimens of AISI 1045 steel.

Figure 3 allows concluding that the thermally treated specimens with a process of hardening-tempering decrease on average a 12.9% the loss of material during the test of abrasive wear. Also can be seen that TiO_2 or Al_2O_3 coatings deposited on AISI 1045 Steel presents a more significant improvement in this property, reaching average reduction of 29.3 and 39.6%, respectively, with respect to standard steel.

To compare the obtained results of abrasive wear tests is calculated the loss of material per unit of linear distance covered, these values are graphed in Figure 4, which shows that for short distances the loss of material of the specimens is more significant, this mainly due to surface roughness caused by the machining of the specimens of normalized and thermally treated steel; and to the irregularity of the coating of alumina made through the process of thermal spray by flame; at greater distances the loss of material is less and tends to stabilize.

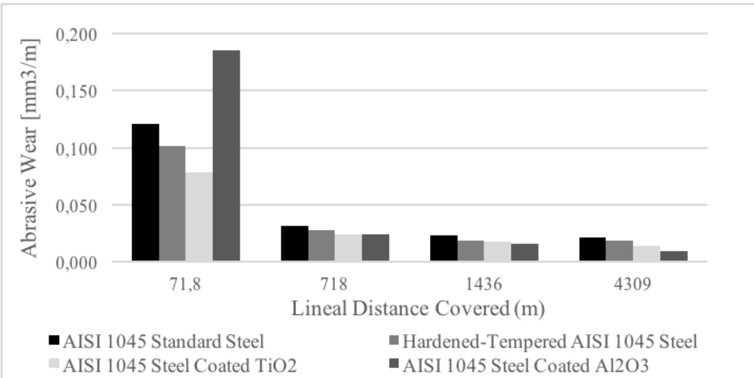


Figure 4. Abrasive wear resistance per unit of distance covered in specimens of AISI 1045 Steel.

5. Conclusions

The process of thermal spray by flame allows the deposition of alumina and titanium dioxide, of nanometric size, on a base material of AISI 1045 Steel, but the use of an anchor material is necessary. However obtained coatings, although they retain their nanoscale dimensions, have a high porosity and discontinuity, which affects the hardness and resistance to wear of them.

The average loss of material, per unit of length travelled, during abrasive wear tests of the standard AISI 1045 steel, thermally treated with a process of hardening and tempering, and coated with Al_2O_3 or TiO_2, nanosized, is 0,0493mm^3/m; 0,0416mm^3/m; 0,0586mm^3/m and 0,0337mm^3/m respectively.

The thermally treated specimens with a process of hardening-tempering decrease on average a 12.9% the loss of material during the abrasive wear test. However titanium dioxide or alumina nanosized coatings deposited on AISI 1045 steel presented a more significant improvement in this property, reaching an average reduction of 29.3 and 39.6%, respectively, with respect to standard steel, this is due to the large capacity of the oxides to resist abrasion.

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