Characterization of Tungsten Carbide coatings deposited on AISI 1020 steel

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Abstract. In order to determine the variation in the mechanical properties of AISI 1020 standardized steel, heat treated by a quenching and tempering process and with a Tungsten Carbide coating, was performed a microstructural and chemical characterization of the coating material through electron microscopy scanning and X-ray energy dispersive spectroscopy. The steel received a heat treatment of quenching performed by heating to 850°C, followed by cooling in water and tempering at a temperature of 450°C with air cooling. Tests of a) microhardness with a Wilson-Wolpert Tukon 2100B micro durometer and b) resistance to adhesive and abrasive wear following the ASTM G99-05 “Standard test method for wear testing with a pin-on-disk machine” and ASTM G65-04 “standard test method for measuring abrasion using dry sand and rubber Wheel” standards respectively. The results show that the microhardness of the steel do not vary with the load used to perform the test; in addition, the heat treatment of quenching and tempering improves by 5.5% the property while the coating increase it by 124.2%. Regarding the abrasive wear resistance, it is observed that the amount of material lost increases linearly with the distance covered. It was determined that the heat treatment decreased on average by 17.5% the volume of released material during the tests while the coating reduced it by 66.7%. The amount volume of material lost during the adhesive wear tests increases linearly with the distance covered while the heat treatment decreased on average by 10.5% the volume of released material during the trial and the coating reduced it by 66.5%.

1. Introduction
The protection of metallic substrates against wear can be achieved by using abrasive and abradable coatings (tribological) composed mainly of ceramic materials [1,2]; the coatings with tungsten carbide (WC) are increasing its use in applications where is required high hardness, good tribological properties, excellent corrosion resistance and high thermal resistance [3-5].

One of the most used processes for applying coatings on metal surfaces is thermal spraying due to its versatility and variety [6,7]; these procedures use a spray nozzle which handles an oxyfuel flame, electric arc or plasma arc [8,9], and allows deposition of both metallic and nonmetallic materials. The progresses of thermal spraying are widely accepted in the industry, both in the manufacture of parts and maintenance, where the application field is extended and increasingly extensive due to the development of new alloys and processes [10].

There are several thermal spraying processes among which stand out: thermal spray wire, metal powder thermal spraying, plasma, trigger gun, high speed spraying with oxyfuel and arc wire; the
coatings obtained have a layered structure of deposited material and can have porosities between 10 and 20% caused by air and oxide particles trapped by high temperatures that are used [8].

In recent years, the manufacture of ceramic nanostructured coatings using nano-crystalline powders has become more technologically attractive due to its excellent properties compared with conventional equivalents [11-13], since by harnessing the properties associated with nanostructures can improve the performance and durability of conventional plasma sprayed coatings that already have a wide variety of applications in aerospace, biomedical, automotive and chemical industry [14, 15]. This paper presents the results of abrasive wear resistance, microhardness and adhesive wear resistance tests conducted on AISI 1020 commercial steel when it is standardized, is heat-treated through a process of quenching-tempering and when is deposited on it a coating of tungsten carbide in powder form of nanometric size.

2. Methodology
The methodology used for the development of the project consisted of 4 stages.

2.1. Morphological and chemical characterization of the WC
It was performed by the technique of Scanning Electron Microscope (SEM) using a microscope of high resolution FE Schottky brand equipped with Field Emission technology for electron emission which has integrated a microanalysis system by energy dispersive X-ray spectroscopy (EDS) which allows to collect X-rays generated by the sample and perform various semi quantitative and distribution of elements in surface analysis.

2.2. Manufacture and preparation of specimens for microhardness and abrasive and adhesive wear resistance testing
The specimens for testing were manufactured from machining process in lathe and milling machine; the geometric shape and dimensions are adapted to the requirements of ASTM E384-11 “Standard test method for Knoop and Vickers hardness of materials”, ASTM G65-04 “Standard test method for measuring abrasion using the dry sand/rubber wheel apparatus” [16] and ASTM G99-05 “Standard test method for wear testing with a Pin-on-disk apparatus” [17] and the equipment used in the different tests.

2.3. Deposition and characterization of WC coatings
The coatings were made through thermal spraying by flame process using an Eutalloy 85 BX gun which is adapted to conventional oxyacetylene combustion equipment. The distance used between the torch and the base material was 30cm with an inclination to the horizontal of 60°. The oxygen and acetylene pressure used was 170kPa and 34kPa respectively, which defines a pressure ratio of 1:5. In order to anchor the coating to the base material a fusible nickel-based alloy is used.

2.4. Testing
The tests were performed on three different specimens: the first were manufactured in AISI 1020 standard steel; the second were of the same steel but thermally treated with a quenching process (heating at 850°C and cooling with water) and tempering (heating at 450°C and cooling with air); and the last were of AISI 1020 steel with WC coating of nanometric size, deposited through thermal spraying by flame process. The microhardness tests are performed following the ASTM E384-11 standard at a Wilson-Wolpert Tukon 2100B micro durometer. The tests of abrasive and adhesive wear resistance are made according to the specifications of ASTM G65-04 and ASTM G99-05 standards, respectively.
Table 1. Testing parameters of abrasive wear.

| Specified Procedure | Force Against Specimen (N) | Wheel revolutions (RPM) | Linear Abrasion (m) |
|---------------------|-----------------------------|-------------------------|---------------------|
| A                   | 130                         | 6000                    | 4309                |
| B                   | 130                         | 2000                    | 1436                |
| C                   | 130                         | 100                     | 71.8                |
| E                   | 130                         | 1000                    | 718                 |

Table 2. Testing parameters of adhesive wear.

| Specified procedure | Force Against Specimen, N | Wheel Revolutions (RPM) | Contact diameter (m) | Linear distance covered (m) |
|---------------------|---------------------------|-------------------------|----------------------|---------------------------|
| A                   | 10.2                      | 3980                    | 0.02                 | 250                       |
| B                   | 10.2                      | 5971                    | 0.04                 | 750                       |
| C                   | 10.2                      | 5307                    | 0.06                 | 1000                      |

The parameters of the tests performance are listed in Table 1 for abrasive wear and in Table 2 for adhesive wear. The measurements of wear are reported as volume loss in cubic millimetres for each one of the specimens used on tests.

3. Results obtained

Based on the images of WC obtained through scanning electron microscopy, is analysed a pre-sample of the dimensions of the side lower than 10 different particles and with them is defined a sample size of 40 data to achieve a reliability of 95% and a maximum error of 5%, the average size of the WC particles was 80.8nm and the distribution is related on Figure 1(a). Chemical analysis of the powders used was performed through the values obtained from microanalysis by energy dispersive X-ray spectroscopy (EDS) which are related in Figure 1(b).

![Figure 1](a)  ![Figure 1](b)

**Figure 1.** Chemical characterization of the particles used in the coating a) Distribution of particles size of WC; b) EDS results of WC particles.

The percentage of error that was obtained between the theoretical and experimental atomic weight obtained by EDS analysis was 3.3% which allows to conclude that the material used in the coatings was WC.

The tests of Knoop microhardness related in Figure 2, allow to conclude that thermally treated specimens with a quenching-tempering process improve by 5.5% this property with respect to normalized steel which is due to the low carbon content of AISI 1020 steel. It can also be observed
that the coating of WC has a more significant increase in this property, reaching a value of 124.2% compared to the normalized steel, this is due to the great capacity of carbides to resist plastic deformation on its surface. Another appreciation that can be obtained of Figure 2 is that Knoop microhardness, for this material, does not depend on the load with which the test is performed.

Figure 3 obtained from the test of abrasive wear resistance allows to conclude that the specimens thermally treated with a quenching-tempering process decreases an average of 17.5% the material loss during the test, while the coated with tungsten carbide reach an average reduction of 66.7% compared to AISI 1020 standard steel. Figure 3 also shows a linear relation directly proportional between the material loss in the specimen and the linear distance covered which is consistent with the behavior of materials to this wear phenomenon.

![Figure 2. Comparison of Knoop hardness in AISI 1020 steel specimens.](image1)

![Figure 3. Material loss during abrasive wear resistance test on AISI 1020 steel specimens.](image2)
Figure 4 obtained from the adhesive wear resistance test allows to conclude that the specimens thermally treated with a quenching-tempering process decreases in average by 10.5% the material loss during the test while the coated with tungsten carbide reach an average reduction of 66.5% compared with AISI 1020 standard steel. The Figure 4 also shows a linear relation directly proportional between the material loss in the specimen and the linear distance covered.

![Figure 4: Material loss during adhesive wear resistance test on AISI 1020 specimens.](image)

4. Conclusions

The thermal spraying by flame process allows the deposit of nanometric sized WC on a base material of AISI 1020 steel but is necessary the use of an anchoring material. However the coatings obtained, although retain their nanometric dimensions, have a high porosity and discontinuity which affects the hardness and wear resistance thereof.

The tests of Knoop microhardness allow to conclude that thermally treated specimens with a quenching-tempering process improve by 5.5% this property while the WC coatings has a more significant increase reaching a value of 124.2% compared to standard steel.

The average loss of material per unit of covered length during abrasive wear resistance tests on AISI 1020 standard steel, thermally treated with a quenching-tempering process and coated with nanometric sized WC is of 0.0382mm³/m, 0.0291 mm³/m and 0.0151mm³/m respectively.

The average loss of material per unit of covered length during adhesive wear resistance tests on AISI 1020 standard steel, thermally treated with a quenching-tempering process and coated with nanometric sized WC is of 0.0827mm³/m, 0.0736 mm³/m and 0.0271mm³/m respectively.
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