https://dx.doi.org/10.22161/ijaers.5.5.32 **ISSN: 2349-6495(P) | 2456-1908(O)**

Adhesive and abrasive wear resistance evaluation of a ABNT 52100 steel from a Stretch Bending Roll coated with WC-Co and NICCr applied by the HVOF Process

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***Abstract*—*The tungsten carbide coatings in the cobalt matrix (WC-Co) and nickel-chromium carbide (NiCCr) are widely used to give greater resistance to abrasive wear to carbon steel. In this work, the possibility of applying these two coatings in the ABNT 52100 steel of a stretch bending roll, with the addition or not of an intermediate NiAl layer, using the thermal spray process HVOF (High Velocity Oxygen fuel), since this process has a small thermal input and allows the possibility of applying a great variety of coatings, including non-metallic ones. It was proposed to evaluate the performance of the samples in situations of high abrasive wear, also evaluating the role of the intermediate layer to improve adhesion of the coating to the substrate. For the evaluation of the resistance to abrasive wear and adhesive, the pin-on-disc tests (ASTM G99-17) and tensile tests (ASTM E8E8M-16a), respectively, were used. The surfaces of the samples were also evaluated by optical microscopy and electronic scanning. In addition, the hardness of each sample was also evaluated. With the tests, it was concluded that the samples with higher hardness and the presence of intermediate layer presented faults in the interface of the substrate with coating, and the resistance to abrasive wear did not deviate much from the values in the literature.*
Keywords*—*HVOF, Pin-on-Disk, Stretch Bending Roll, ABNT 52100.

I. INTRODUCTION

The field of engineering that studies the use of coatings over metal components has been growing over the years due to the cost of structural materials and life cycle requirements of high performance components. Carbide based coatings applied by thermal spraying are used in the aeronautics, automotive, oil and steel industries. Thermal spraying is referred to as a group of processes in which finely divided metallic or non-metallic materials are deposited in a molten or semi-molten condition on a prepared substrate to form a sprinkled deposit [1]. According to Papst[2], as part of the industrial knowledge about the processes of coatings by thermal spraying is practical, this study is the result of the need to evaluate the effect of the use of intermediate layers and the choice of the coating with better resistance to abrasion, thus enabling both material savings and increased performance of mechanical components.

The study of this work is characterized by the occurrence of displacement problems in the coating process carried out by SMS Group® on rolls of a forming machine. This machine is, as shown in Figure 1, a tensioning planer present in the pickling area of the milling process of a steel mill. The roller needs a high hardness and resistance to wear, since it works in contact with the steel coils for its performance.

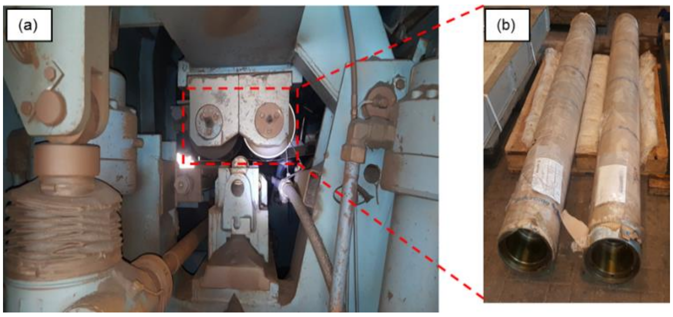

Fig. 1: Studied equipment. a) Stretch bending; b) Roll

https://dx.doi.org/10.22161/ijaers.5.5.32 ISSN: 2349-6495(P) | 2456-1908(O)

II. BIBLIOGRAFIC REVISION

High Velocity Oxygen Fuel deposition (HVOF) is based on a special torch design, as shown in Figure 2. In it, oxygen and fuel are burned, thus melting the powder that also enters the combustion chamber axially. The flame expands through the nozzle at the end of the combustion chamber, which causes it to reach high speeds. According to Ladeira[3], after the impact the particles flatten and adhere well to the substrate and neighboring particles, making the coating dense and with good adhesion.

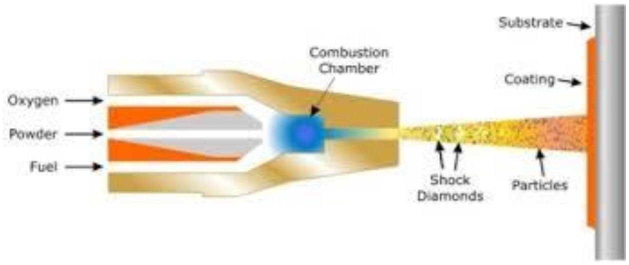

Fig. 2: HVOF thermal spray torch.

According to ASTM [4], the specimen typically used in this test is regular in shape of 25 mm wide by 76 mm long (1 by 3 in) and a thickness of 3.2 mm to 12.7 mm (0.12 to 0.50 in). The wear is evaluated through the mass loss which is subsequently converted to volumetric loss through Equation 1.

$$VolumetricLoss(mm^3) = \frac{Massloss}{Density\ (g/cm^3)} x1000 \qquad (1)$$

A widely used method of abrasive wear evaluation is the Pin on Disc test, governed by the standard ASTM [5], which consists in positioning a pin or a sphere of certain material and with certain dimensions perpendicularly on a moving disc. The pin typically used in the test is cylindrical in shape and has a spherical tip, having a diameter of 2 to 10 mm, whereas the disk has diameters ranging from 30 to 100 mm and thickness from 2 to 10 mm.

There are some ways to assess the wear resistance of a material. One of the simplest and most effective ways is the evaluation through the tensile test. This test, as stipulated in the standard in ASTM [6], consists of subjecting a test piece, of standard dimensions, to an axial load of increasing value until its rupture. It gives the value of the elongation of the test piece as a function of the applied load. This makes it possible to compare the maximum load supported by a given material, as reported in the catalog, without detachment of the coating with the actual maximum load the material supports being subjected in a tensile test to the point of detachment.

III. METHODOLOGY

For the wear resistance analysis of the proposed materials, the results of abrasive wear and adhesive tests, hardness and Scanning Electron Microscopy (SEM) of four samples were compared, according to Table 1.

Table 1: Samples used in the tests.

	Hardening	*Middlelayer*	*Coating*
Sample 1	60 HRC	NiAl	WC-Co
Sample 2	60 HRC	NiAl	WC-Co + NiCCr
Sample 3	30 HRC	----	WC-Co
Sample 4	30 HRC	----	WC-Co + NiCCr

The HVOF thermal spray process was carried out at SMS GROUP ® using equipment manufactured by GTV®, consisting of the JP500 torch, integrated blasting and GTV-PF 2/2 WH powder feeder, according to Figure 3.

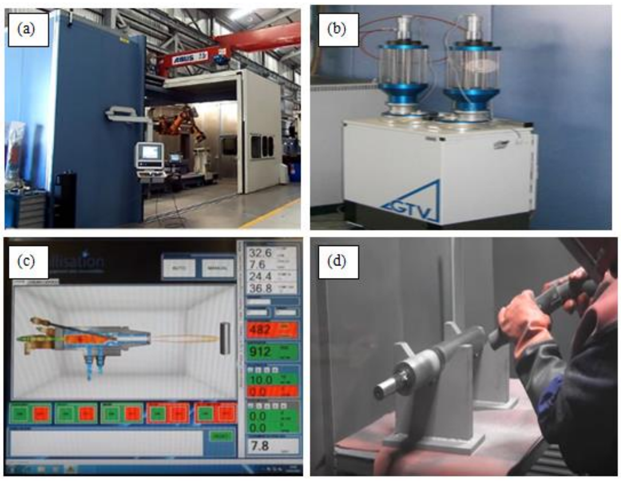

Fig. 3: HVOF Equipment. a) Thermal spray cabin; b) Powder feeder; c) Monitor; d) Integrated blasting.

In order to evaluate the sample's abrasive wear resistance, the Pin-on-disc test[5]was used, with the disc rotation value 1000 rpm, normal force against the disc of 10N, ball diameter of 10 mm made of hard metal and 20 minutes test time for each sample. For the resistance to abrasive wear, the sample test model with rectangular basewas used, according to Figure 4.

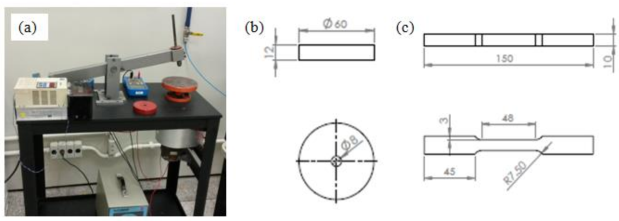

Fig. 4: Tests implementation. a) Pin-on-disk equipment; b) Disk dimensions; c) Tensile test sample dimensions.

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IV. RESULTS ANALYSIS

After the hardening process in oil or salt, the microstructure changed to martensitic, as can be observed in Figure 5, with approximately 3 to 4% of undissolved cementite and 6% of retained austenite [7].

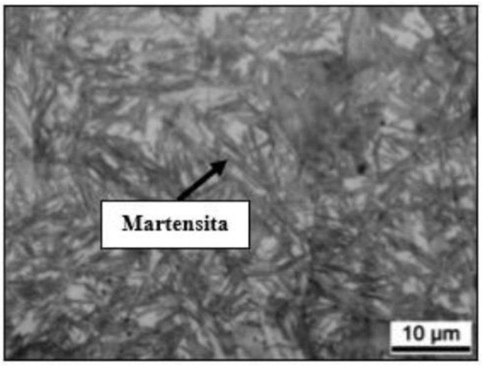

Fig.5: ABNT 52100 microstructure after hardening.

It can be observed that samples 1 and 2 - which have the highest substrate hardness and the presence of a coating intermediate layer - showed mechanical anchorage faults of the particles sprayed at the coating interface with the substrate. One of the justifications for this unsatisfactory result is the fact that the particles, when hitting the substrate, find it more difficult to plastically deform it since the material has a high hardness, making it difficult to anchor.

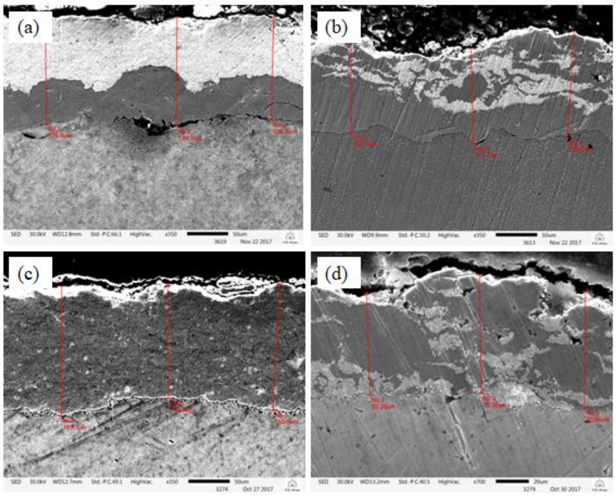

Fig.6: Scanning Electron Microscopy (SEM).
a) Sample 1; b) Sample 2; c) Sample 3 and d) Sample 4.

With the values of mass variation obtained after the pin-on-disc test, the value of the volumetric loss was calculated by density equation, its approximate value for the coatings is 14.03 g/cm³[8]. Analyzing the results of Table 2 and comparing them with the typical value provided by [1]for WC-Co sprayed by HVOF of 0.9 mm³, we can see that the values found are not very far from the expected values for the coatings studied.

Table 2: Abrasive wear rate.

	M_{Antes} (g)	M_{Depois}(g)	ΔM (g)	ΔV (mm³/1000rpm)
Sample 1	277,686	277,645	0,041	2,9223
Sample 2	272,512	272,487	0,025	1,7818
Sample 3	243,651	243,644	0,007	0,4989
Sample 4	234,727	234,715	0,012	0,8553

By performing a visual analysis, as can be seen in Figure 7, samples 1 and 2 presented good performance in relation to the adhesive wear, since they did not suffer any failure by coating displacement, not even in the imminence of rupture. Samples 3 and 4 have presented displacement of the coating.

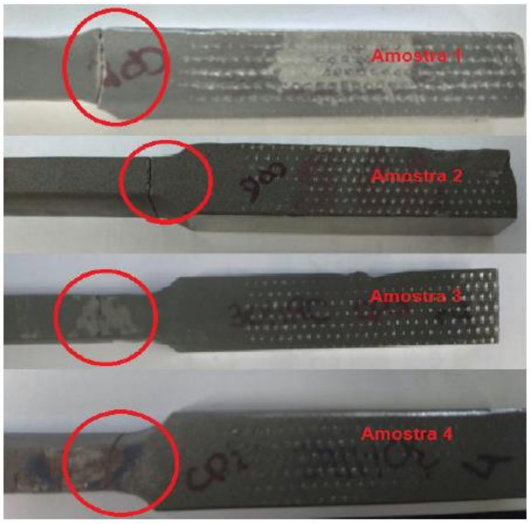

Fig.7: Samples after the tensile tests.

One of the spare samples ruptured during the machining process, even before the tensile test was carried out; which suggests that the samples are actually fragile in relation to the impact load and not to the application of loads in a continuous way. For this evaluation, it will be necessary to carry out a Charpy impact test. Another point that could have caused the rupture of the sample would be the concentration of stresses due to previous attempts of tensile test and possible influences of the type of cutting process used.

V. CONCLUSION

As for the evaluation of the coating adhesiveness to the substrate, after the tensile test it was found that samples 1 and 2 showed satisfactory performance. On the other hand, the samples 3 and 4 were observed displacements near the region of rupture. With respect to the voltage results obtained, it was observed that in samples 1, 2 and 3 the values were even higher than those specified in the material datasheet. However, the document does not state under what conditions and what type of assay was used for such outcome, which makes the analysis difficult.

In the SEM analysis, it can be concluded that in samples 1 and 2 in which the intermediate layer was used, the presence of voids and faults in the interface between the coating and the substrate was observed. Therefore, it is necessary to control mainly the roughness and temperature of the process, since this roughness has a direct influence on the results, because depending on the value used, this difference of peaks and valleys can lead to this type of problem.

As for abrasive wear, it can be concluded that all samples meet the technical specification, as they have a relatively low wear rate relative to the reference values. Regarding the type of coating, it is verified that tungsten carbide was more efficient presenting a lower rate of wear, as observed in sample number 3 of Table 2, due to the high hardness and abrasion resistance provided by tungsten carbide.

Considering that all the samples were submitted to the same coating parameters - parameters of the thermal spray by HVOF, blasting, preheating, etc. - it can be affirmed that under current conditions there is excessive use of resources such as time and money spent in the hardening of high hardness and application of intermediate layer of coating without obtaining a result of better quality.

ACKNOWLEDGEMENTS

To the SMS Group ® who welcomed us and who attended us whenever we needed.

To the CNPQ and FAPEMIG for the assistance that made this work feasible.

To PUC Minas, for allowing the use of its laboratories and facilities.

To the Center for the Development of Nuclear Technology (CDTN), for allowing the use of the Mechanical Tests Laboratory.

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