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HVOF-SPRAYED COATING AGAINST WEAR OF SLURRY PUMP ROTORS AND TAILINGS FOR THE COAL MINING INDUSTRY

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Abstract. *Separating the coal from the refuse, which is often accomplished using a cyclone, is a crucial stage in the processing of mineral coal. With a relative density of 1.8 to 1.9, the fragmented and pre-concentrated mineral is transports by the slurry pump to the inside of the cyclone. The slurry pump rotor typically lasts 30 days, during which time the substrate material must be partially recovered and completely coated. Surface coatings are a good way to improve rotor wear resistance. These coatings improve abrasion resistance and slowing down the surface degradation brought on by abrasive and erosive wear. To compare the coating used in a coal mining industry, was used a stainless steel AISI 316 rotors coated with WC-10Co-4Cr and WC-10Ni using the high velocity oxygen fuel (HVOF) spraying method. The primary goal of this study is to examine the tribological behavior of these coatings through field testing. To evaluate the tribological performance of these alloys in situ in the coal processing facility with a capacity of 70 t/h, two rotors were produced. The key finding was that, in comparison to the rotor coated with silicon carbide (SiC), the wear rates on the WC-10Ni and WC-10Co-4Cr coatings were reduced, with WC-10Ni standing out. Material removal was seen by scratching at the rotor outlet while minor delamination was found in other places when examining the abrasion processes beneath the coatings and substrate. Another important observation was that when exposed to abrasion in the slurry pump, the samples lost a substantial amount of volume because of erosive wear, being 76% lower with WC-10Ni and 38% lower with WC-10Co4Cr.*

Keywords: *Pump rotor, Erosive Wear, Abrasive Wear, HVOF, WC-10Ni, WC-10Co-4C*

1. INTRODUCTION

Two centrifugal pumps are used in the processing of coal: a tailings pump that has a semi-open rotor, and a slurry pump has a closed rotor. Currently, AISI 316 stainless steel is used as the pump rotor substrate, because of its excellent mechanical properties and high corrosion resistance. Silicon carbide has been applied to the surface of these rotors to lessen surface wear. Due to the significant wear of the rotor, which affects the functionality and lifespan of this equipment, the average operational time of the tailings rotors is 15 days and that of the slurry pump rotor is 30 days. It was discovered throughout the investigation that the components have suffered a significant wear from corrosion, abrasion, and erosion. According to research published in 2016 by Ferreira, the combined effects of abrasive and erosive wear are highly damaging to materials like stainless steels that have a coating protecting them from oxidation.

Abrasion, erosion, adhesion, surface fatigue, and tribochemical reaction, sometimes known as corrosion-wear, are the four distinct wear processes identified by DIN 50320 (Bayer, 2004). The contact between the particle and the surface and the source of the forces are what differentiate erosive wear from abrasive wear. In terms of the length of the particle's contact with the surface, abrasion results in a greater contact time than erosion. When it comes to the forces within the particle, abrasion involves the particles being forced against the surface on which are sliding, whereas erosion involves the particles being decelerated when they impact with the surface (Ferreira, 2016).

Because the mud flows and impacts the rotor, causing erosive wear, it is crucial to consider the particle's hardness, amount, size, geometry, impact speed, and angle. The elements that affect the wear of pump components are as described by Figueira Júnior (2017): The mode of operation: concerned with regulating the rotor concentricity, the pump's speed, and its power; Design: relates to the shape and materials used in construction. Process: relates to the fluid and particle characteristics as well as the pressure and flow rate at which the pump operates.

Thapa *et al.* (2008) state that tungsten carbide (WC) and its alloys are the coatings frequently used to increase wear resistance in pumps, and they suggest that increasing surface hardness is an effective and efficient way to mitigate damage. In comparison to alternative thermal spraying methods, the HVOF technique offers several advantages, including improved wear resistance, more adhesion to substrate, reduced oxide content, higher hardness, and lower porosity (Pukasiewicz *et al.*, 2012). The high impact speed of the particles on the substrate is another advantage of HVOF. This suggests that a high-quality covering may be produced even when the particles are not entirely fused. Furthermore, because there is no overheating, residual stress issues are reduced, which is important for internal diameters and thick coatings (Lima & Trevisan, 2007).

The purpose of this research is to increase the performance of the rotor of a slurry pump used to drain the residue removed from the coal mine since doing so would decrease maintenance costs and increase rotor life. The performance of the coatings applied to the rotor surfaces, using WC-10Co4Cr and WC-10Ni alloys sprayed using the HVOF technique, was assessed to enhance the operating conditions of these rotor. The wear coefficient was therefore measured using field testing that enabled quantifying the improvements as well as doing a cost-benefit analysis with the change in the coating.

2. EXPERIMENTAL PROCEDURE

The three aspects that Figueira Júnior (2017) explores are: its mode of operation, design, and process. These characteristics will serve as the starting point for the study activities. The performance of WC coatings sprayed using the HVOF thermal spray is then compared to the performance of the existing coating, which is manually coated with SiC.

2.1 Pump operation mode

The rotors are balanced and concentric when they are in operation. An electric induction motor, powered at 440 V, of 40 HP and a rotation speed of 1750 rpm, is used by slurry pump. An electric motor also induction with same characteristics, but with 100 HP, drives the tailings pump. In Figure 1, worn rotors are compared with new ones.

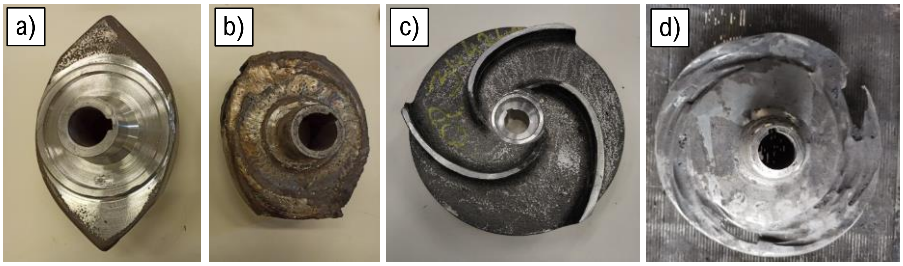

Figure 1. New and used pump rotors a) new slurry pump rotor recovering slurry pump rotor, b) maintenance slurry pump c) new tailings pump rotor, and d) severely worn tailings pump rotor.

Stainless steel welding is used to repair the rotors' damaged surfaces and the interior of the housing during maintenance. Following this procedure, a SiC mass is applied to these surfaces, then the rotors are balanced and put together. The centrifugal slurry pump introduces the separator cyclone, a centrifuged ground material, during operation. Gravity causes the heavier particles to descend and separate from the lighter ones, which then float up via a tube to coal with a lower density. The semi-open rotor centrifugal pump moves the leftover material to different areas for subsequent disposal. A slurry pump used is shown in Figure 2a, and in Figure 2b the pump is shown with the casing open.

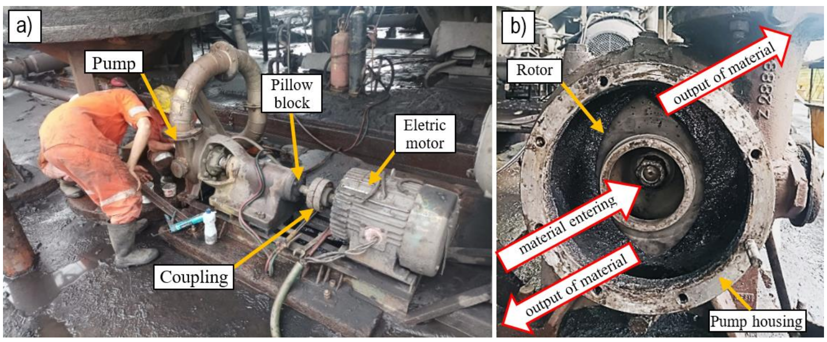

Figure 2. Centrifugal pump assembly a) external view and b) internal view.

2.2 Characterization of rotors

The slurry pump's rotor was closed, whereas the tailings pump's rotor was semi-open, as was noticed in the characterization of the rotors. Traditionally, stainless steels AISI 316, which has a high molybdenum content and has strong resistance to oxidation and abrasive wear as its key properties, are used to made the rotors. To lessen wear, Silicon Carbide (SiC) is applied to the interior pump housing surfaces prior to assembly.

Slurry and tailings pumps are seen in Figure 3 in both their new and worn-out forms. While rotors are semi-open, slurry rotors are closed.

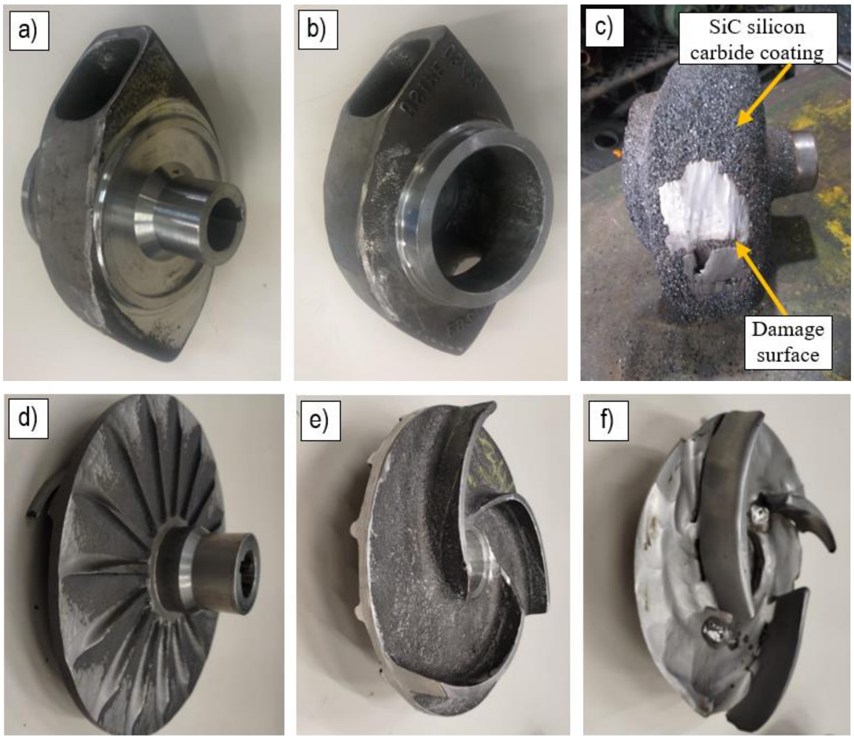

Figure 3. View of pump rotors from various angles: a) slurry rotor shaft side, b) flow inlet side of slurry pump rotor, c) worn and damaged slurry pump rotor, d) side of the tailings rotor shaft, e) flow inlet side of the tailings rotor, and f) tailings rotor with welded and worn blades.

The rotors were made using stainless steel that is AISI 316. This material was chosen because a large concentration of high-hardness particles with geometric forms that encourage abrasive wear are present on the solid component, in addition, occur a flow on the surface of a mixed fluid with high corrosion. Other ferritic and martensitic stainless-steel alloys have been tried, but they did not exhibit good corrosion resistance, as stated by the mining sector. The usage of these alloys reduced the bond strength of the SiC coatings, weakening their protective layer, due the chemical reaction occurred on the metallic surface.

2.3 Characterization of coal tailings

A chemical analysis of the slurry coal was during the research to evaluate the composition of elements that could influence wear. The tailings material contains significant amounts of ceramics with high hardness even though the ground material is coal. The X-ray fluorescence spectrometer (FRX) was used to assess the slurry composition of the mineral material and determine the relation between the components and the quantity in the sample. In Table 1, the composition and quantities are presented.

Table 1. Chemical composition of slurry.

Composition	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**K_2O**	**CaO**	**TiO_2**	**Fe_2O_3**	**SO_3**
Quantities (%)	0,77	2,37	23,31	68,61	0,001	3,44	2,28	0,69	5,27	2,65

The fraction of the most aggressive elements on the surface is disclosed by this information, which makes it pertinent. For instance, SiO_2 (68.61%) has a microhardness of between 1100 - 1200 HV, while Al_2O_3 (23.31%) has a microhardness between 1400 and 1800 Vicker's. Thus, the alumina particles (Al_2O_3) have the highest hardness in the mining material.

According provided by the company, the coating on the pump rotors is made of a chemical composite based on silicon carbide, or SiC. The analysis performed using Energy-dispersive X-ray spectroscopy (EDS) provided the result shown in Table 2, identifying a composite material. Furthermore, the carbon content is significant due to the punctual detection of the EDS and the epoxy material that is part of the alloy.

Table 2. Chemical composition of silicon carbide coating (wt.%).

Composition	**Fe**	**Al**	**Si**	**Ti**	**Mn**	**Cl**	**Ca**	**K**	**Zr**	**Er**	**Cr**	**Cu**	**Zn**	**Sr**	**C**
Quantities (%)	19.60	16.48	6.70	0.39	0.22	0.20	0.17	0.12	0.02	0.04	0.04	0.02	0.01	0.01	55.89

The fluid's flow direction and how it appears after it has completed its operation were examined, along with the surfaces that exhibit the most wear-related damage.

2.4 Setting up experimentation activities

The tests were conducted in two parts, the first of which took place in the UniSATC laboratories. Field testing were conducted in Step 2. At the Carbonífera Metropolitana S/A facilities, tests with coated pumps were performed. The phases in Figure 4 shows how the research's approach was implemented.

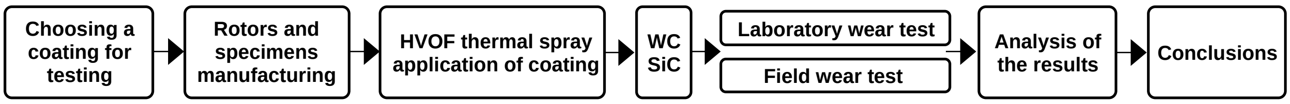

Figure 4. Planning for carrying out the experimentation.

2.5 Selection of coatings for testing

Based on the findings of a prior study in which abrasive wear tests were conducted using the ASTM G65 standard, coatings were chosen. Bauer *et al.* (2021) examined and contrasted the abrasive wear resistance of the alloys Cr3C2-25NiCr, WC-10Co4Cr, and WC-10Ni. The prior work is continued in this research.

Bauer *et al.* (2021) tested the rubber wheel and sand tribometer for abrasive wear. Comparing the volume loss of WC-10Ni and WC-10Co4Cr coatings with SiC, it was shown that WC coatings are 40 times more resistant to abrasive wear than SiC. Furthermore, compared to WC-based coatings, which had essentially the same coefficient of friction (~ 0.25), the SiC coating had a coefficient of friction (COF) that was about twice as high (~ 0.5).

Using the ASTM G99 standard and pin-on-disk tests, Bauer *et al.* (2021) also assessed the coefficient of friction. A zirconium oxide spherical was utilized as the pin. For WC-10Co4Cr and WC-10Ni with comparable behavior, the average coefficient of friction was 0.6 and for SiC, it was 0.3. WC-10Co4Cr and WC-10Ni coatings were applied to AISI 316 steel rotors and AISI 304 specimens for abrasion and adhesive testing.

2.6 Preparing Specimens for Lab and Field Tests

The surface must have a consistent metallic hue throughout and be devoid of visible dirt, oils, and grease when viewed with the naked eye (Belém *et al.,* 2020). Thus, used aluminum oxide (Al_2O_3) to blast the rotors before to the application of coatings by HVOF.

The tailings and slurry rotors were supplied by Carbonífera Metropolitana S/A and are made of AISI 316 stainless steel. Then, two more rotors with a similar design to the earlier ones were produced. On the side of the surface opposite the fluid inlet of the original rotor, two holes were found. These holes match to casting process faults. With some changes from the foundry material, the holes were filled with AISI 304 stainless steel welding. Because filling with AISI 304 weld to the AISI 316 rotor created a more vulnerable region. This casting failure had a significant impact on the outcomes. The composition percent of the AISI 304 and 316 steel alloys are displayed in Table 3. The main difference is that stainless steel 316 contains 2 to 3% molybdenum.

Table 3. AISI 304 and 316 stainless steel alloy weight %. Adapted from Gerdau (2021).

Material	**%**	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**N2**	**Mo**
AISI 304	Min. - Max.	0.07	0.75	2.00	0.045	0.300	17.50 - 19.50	8.00 - 10.50	0.10	--
AISI 316	Min. - Max.	0.08	0.75	2.00	0.045	0.300	16.00 - 18.00	10.00 - 14.00	0.10	2.00 a 3.00

2.7 HVOF coating deposition process and parameters

Layers of molten, semi-molten, or solid particles are applied to a substrate via thermal spray. The material is injected into the heat source (gas combustion, electric arc, or plasma) as a powder, wire, or rod. Gas expansion accelerates the particles, which are then projected into the substrate at a high velocity. This results in a high impact energy and quick cooling. This results in a covering with many layers of thin particles overlaid (Bergmann and Vicenzi, 2011).

The coating was applied at the Rijeza Metalúrgica company employing equipment from the PRAXAIR manufacturer, the TAFA JP 8000 HP/HVOF System. Options for this procedure include layer thickness, lamellar structure, and porosity, among others. Table 4 shows the parameters that were used.

Table 4. Main parameters used in the HVOF thermal spraying process.

Parameters	Feed rate	Oxygen pressure	Oxygen flow	Fuel pressure	Distance from gun to specimen	Compressed air pressure	Coating thickness
Value	38 g/min	150 PSI	578 scfh	100 PSI	230 mm	100 PSI	0.2 mm

2.7.1 Microhardness tests

A Shimadzu model HMV-2T microhardness tester was used to carry out the Vickers microhardness tests, and a force of 980.7 mN ($HV_{0.1}$) was applied for 10 seconds. To evaluate the microhardness profile of the cross sections, four indentations in the coatings and eight along the substrate were produced. The indentations began at the coating's surface, go through a potential heat-affected zone, and finally finish in the substrate.

2.7.2 Microstructure

The characterization of the coatings was performed by optical microscopy (OM) with the OLYMPUS model BX 51M microscope, and supplemented with energy dispersive spectroscopy (EDS), model QuantaX, to quantify the chemical elements of the coatings. Using the model EDX 7000 apparatus and the X-ray fluorescence (FRX) technology, the chemical content of the coating was identified.

2.8 Field tests

In the field testing, WC-10Co4Cr and WC-10Ni-coated rotors were employed to investigate the wear characteristics brought on by the carbon pulp's interaction with them. These rotors were set up at the coal beneficiation run by Carbonífera Metropolitana SA company. For the slurry rotor and the tailings rotor, the test basically consisted of determining the mass loss after operating for 15 and 30 days, respectively. The setting where the test rotors were set up is seen in Figure 5.

Figure 5. Location of field tests (a) beneficiation plant (b) slurry pump rotor undergoing maintenance.

Equation 1 is used to determine the volume of material worn (Vr) during the test after the mass has been removed and considering the specific mass of the surface. The setting where the test rotors were mounted is seen in Figure 5.

$$V_r = \Delta m / \rho_r \quad (1)$$

Where V_r, Δm and ρ is the volume removed from the specimen (mm^3), the mass variation after the test (g) and the specific mass of the coating (g/mm^3), respectively.

The average density of WC-10Co4Cr, WC-10Ni and SiC coatings are 12.89; 14.38 and 2.3 g/cm^3 respectively. While the density of AISI 316 stainless steel is 8.0 g/cm^3.

3. RESULTS AND DISCUSSIONS

Complementary information was supplied by the laboratory and field experiment outcomes. Image and data were used to compare the performance of the coatings while presenting the results. The slurry rotor maintained a spin of 1750 rpm throughout the testing. The maintenance frequency for the pumps was 30 days, although this time depends on Carbonífera Metropolitana S/A's requirement for production. The test period for the tailing’s rotors lasted 15 days and to slurry rotors were 30 days.

3.1 Microstructure and Microhardness Profile

The substrate had an average hardness of 195 ± 10 $HV_{0.01}$ with these non-uniform variations or indicating a pattern, and none of the studied specimens revealed a thermally affected zone or change in substrate hardness. The microstructure of the samples' cross-sections for the three coatings applied by thermal spraying is shown in Figure 6, along with a comparison to the currently in use coating made of SiC particles dispersed in an Epoxy matrix.

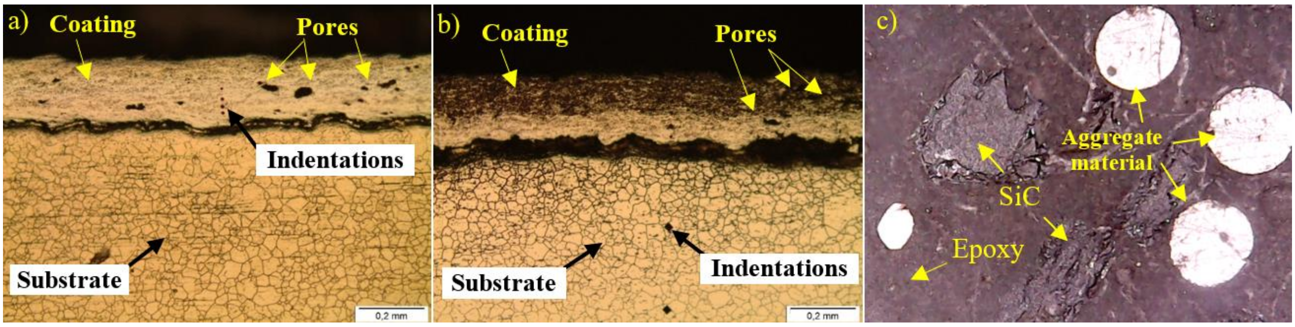

Figure 6. Cross-section microscopy. a) WC-10Ni, b) WC-10Co4Cr and c) SiC particles dispersed in an Epoxy matrix

WC-based coatings, applied via HVOF, form a distinct layer between the coating and the substrate with the mechanical anchoring of the latter to the substrate. According to Voyer and Marple (1999), the WC-10Ni coating and others based on WC exhibit porosity lower than 1%, which describes as denser and stronger resistance to wear since the pores might frequently be the beginning place of a mechanism's scratching or grooving.

Figure 6c shows the images with an optical microscope, in which three distinct elements forming the SiC and Al_2O_3 coating can be seen. Epoxy is the resin that predominates in terms of its dark hue; a hardness measurement was not feasible. While the spherical material is a mineral aggregate with different diameters and an average hardness of 900 ± 100 $HV_{0.01}$, probably alumina, according to results Table 2. While the amorphous material is silicon carbide grains with a hardness of 4650 ± 850 $HV_{0.01}$. Figure 7 shows the results of measurements of the hardness profile of the WC compounds in Figures 6a and 6b.

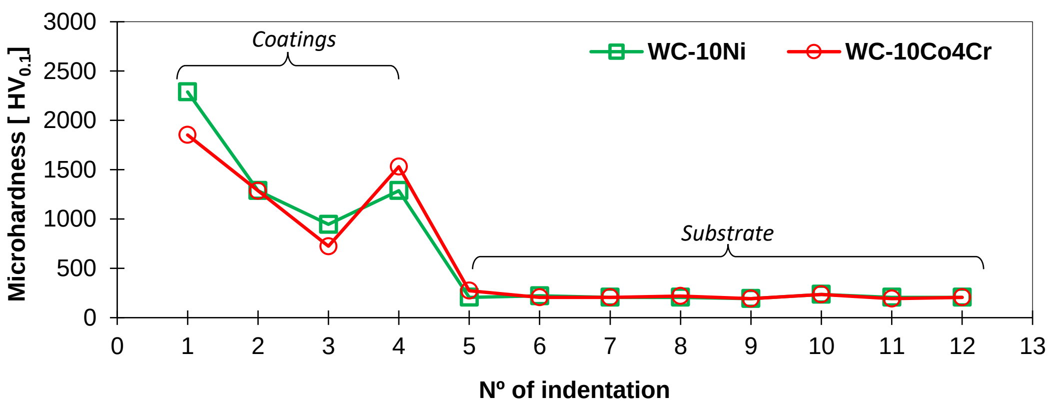

Figure 7. Microhardness profile for WC coatings obtained from the surface to the core of the specimen.

It was observed that the substrate does not change in the matrix, which proves that there is no zone thermally affected by the application of the coatings, keeping the microhardness value practically constant. The WC-based coatings showed similar behavior, with a slightly higher microhardness value at the end of the WC-10Ni coating and while advancing towards the substrate this microhardness decreases and close to the substrate it grows again. Studies by Thakur and Arona (2013), Goyal *et al.* (2012), Bobzin *et al.* (2018), present hardness values close to those acquired in the results of the coatings studied here. High microhardness tends to reduce wear, if the surface is not weakened, and cracks do not occur due to surface fatigue.

3.2 Fiel test results

The tests considered the average monthly operating time of the coal preparation plant. The qualitative and quantitative analysis of the rotor has made it possible to have a more detailed understanding of the wear mechanisms affecting it. Additionally, it will enable comprehension of the degree to which friction and wear are influenced by geometry and operational dynamics (Figueira Júnior, 2017).

3.2.1 Visual evaluation

The WC-10Co4Cr-coated rotor was put into the slurry pump and used for 17 days, losing a total of 1395 (g) during that period (Figure 8). The rotor that was manually coated with SiC exhibits a mass loss of 3950 (g) after 30 days when coating and substrate material loss are considered. The WC-10Co-4Cr coated rotor was separated into three sections in the front view of Figure 8a. While the WC-10Ni-coated rotor ran for 25 days and lost 789 g, it behaved similarly to the WC-10Cr-4Co-coated rotor with less side wear. The wear study of the WC-10Ni coating also is shown in Figure 8. The rotor also was separated into three areas.

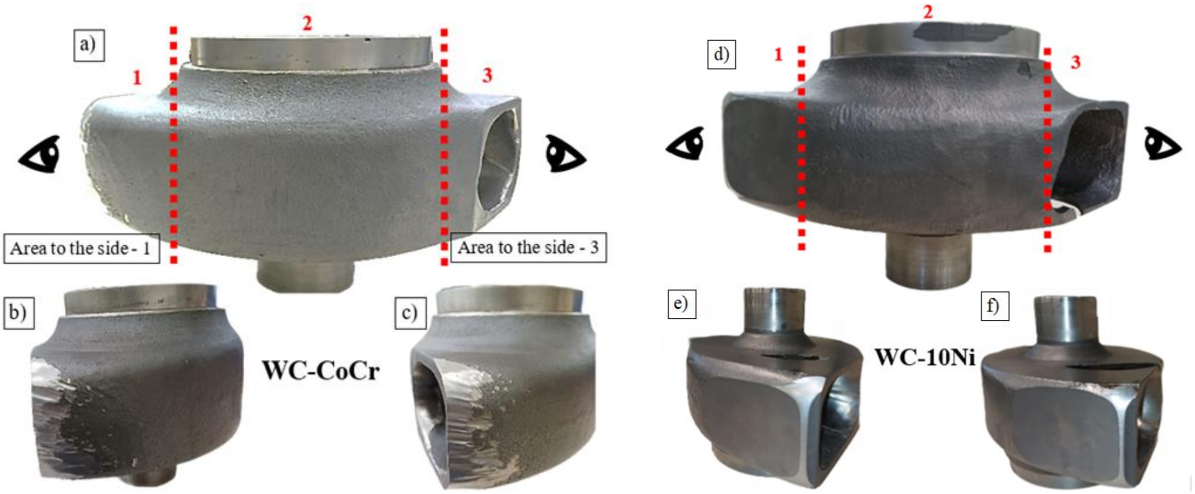

Figure 8. Rotors coated with WC-10Co-4Cr and WC-10Ni. (a, d) Division into 3 sections. (b, e) and (c, f) wear and detaching.

In section 2 for WC-CoCr, no significant wear was observed, but in sections 1 and 3 there was notable wear. The test rotor's damage and the loss of mass at the ends of the rotors are depicted inside views in Figures 8b and 8c. Additionally, it should be observed that several areas have extreme wear for WC-CoCr coating, emphasizing the rotor surface's side. It is evident that the quantity of scratches for this coating that have been observed and the fact that the coal slurry causes abrasive and erosive wear, however, indicate that corrosion mechanisms is not a major problem.

The analysis of surface, mostly for WC-CoCr but also for other materials, is shown in Figures 8b and 8c, and it supports the similarity between the various sections. In these, it is observed that the wear mechanism is abrasive, characterized by the grooves and scratches that stand out, oriented in the same direction as the flow of the material. It is also observed that displacement appears in some parts.

The WC-10Cr-4Co-coated rotor differs from the WC-10Ni-coated rotor in that the outer section is entirely curved on the former while a portion of the latter is flat at the slurry exit zone. This modification most likely protected the pulp on the exterior from being scratched.

Both similarities and differences may be seen upon visual evaluation of the wear between the two WC-10Co4Cr and WC-10Ni coated rotors. The biggest difference with the coating with SiC was that the wear of this one occurs in many regions at the same time, but in the ones coated with WC it occurs in some parts in an accentuated way and in other parts it is not noticeable if wear has occurred.

The WC-10Co-4Cr and WC-10Ni-coated rotors are shown in Figure 9 to have significant wear at the rotor outlet. This failure is caused by the centripetal force, in which bigger particles tend to move toward the center of the rotor and impact the surface there.

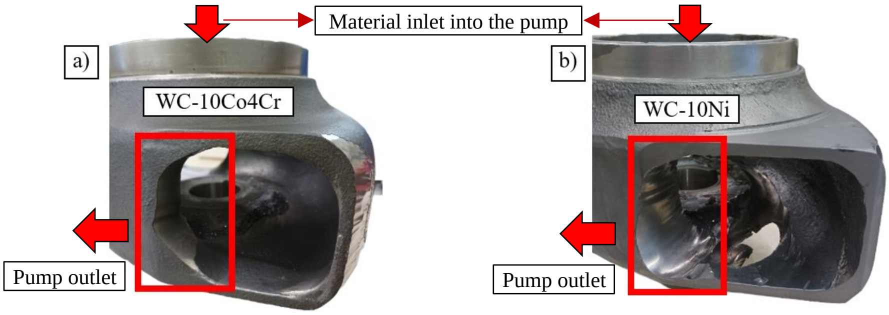

Figure 9. Wear on the inner outlet of coated rotors made of (a) WC-10Co-4Cr and (b) WC-10Ni.

According to Figueira Júnior (2017), erosive wear develops because of the particle's hardness, amount, size, and shape, pumping speed, and angle of impact. In addition to the intrinsic qualities of the particles in the fluid, the form, composition, and operating speed of the pump affect its level of wear to a greater or lesser extent. Peat *et al.* (2016) report in their study that samples coated with WC-10Co4Cr had volume loss under erosion that was five times less severe.

The WC-10Ni coated rotor is seen in Figure 10a. On the surface it is possible to notice a large hole, the result of a failure in the casting process. The rotors were made of AISI 316, and these voids obtained after the machining process were filled with AISI 304 weld. In the image it is evident that there was a lot of wear in this region. Due to the difference in the material properties, the substrate did not have a good anchorage, and this was the beginning of the detachment of the weld and coating, generating a great loss of material. As can be observed in Figure 10b, the WC-10Co-4Cr-coated rotor had no substrate defects on its surface.

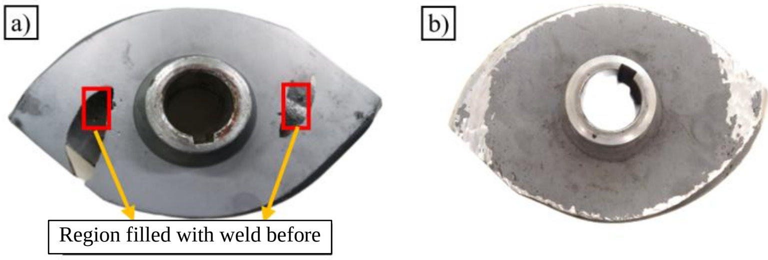

Figure 10. Comparison of wear on rotors a) coated with WC-10Ni and indication of the welded part on the rotor and the highlight of the wear that crosses the surface b) coated with WC-10Co-4Cr.

This study demonstrates that the impact angle has a significant influence on how well any material performs for the erosion wear mechanism. Hardness becomes a dominant attribute for limiting damage at lower impact angles because less energy is delivered to the material. Due to this, a ductile material with a lesser hardness will suffer more damage at a lower impact angle, whereas a higher impact angle will transmit more energy to the material. Other characteristics, like toughness or fatigue resistance, thereby regulate damage. A brittle material with lesser toughness will suffer greater damage at a higher impact angle as a result. The experimental findings from Chauhan *et al.* (2010) indicates that the WC-10Co-4Cr coating becomes fragile and has more erosion losses at 90°.

Smooth surfaces prevail in all the images of rotors, with a few noticeable imperfections induced by the passage and removal of material brought on by the interaction of the slurry and the coal. The coating layer in both rotors turned out to be inadequate to keep the rotor operating for extended periods of time.

Another case study was with the tailing's rotor coated with WC-10Ni, and installed in the pump, as show Figure 11.

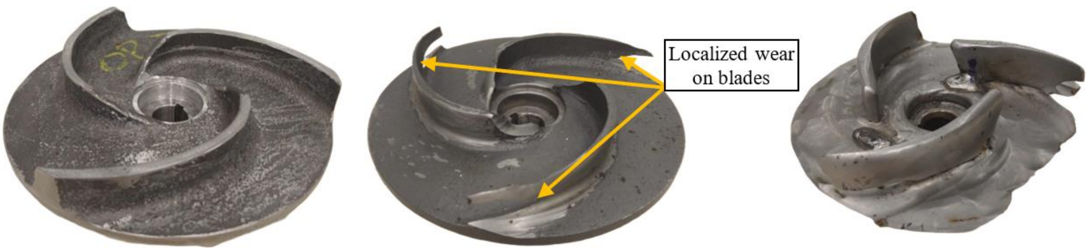

Figure 11. Comparison of tailings rotor a) new, b) used coated with WC-10Ni and c) used coated with SiC.

This rotor operated for 17 days and lost 386g of mass, while the one coated with SiC, operating for 15 days, had 1825g of material removed. Figure 11 compares the wear following testing. Figure 11a shows the rotor unused, whereas Figure 11b shows it coated with WC-10Ni. This rotor had significant localized wear at the ends of the blades, being little affected in other parts of the surface. In Figure 11c, the one that was coated with SiC is shown. It is completely worn out, so its blades had to be welded to have a complete image of this rotor.

4.4.2 Volume loss and rotor wear rate

Equation 1, which calculates the volume loss, divided by the operation time, divided by the number of rotations, was used to determine the wear rate for each kind of sample. Therefore, the lower the index, the more wear-resistant the coating would be. Volume loss values per rotor revolution for each pump type are shown in Figure 12.

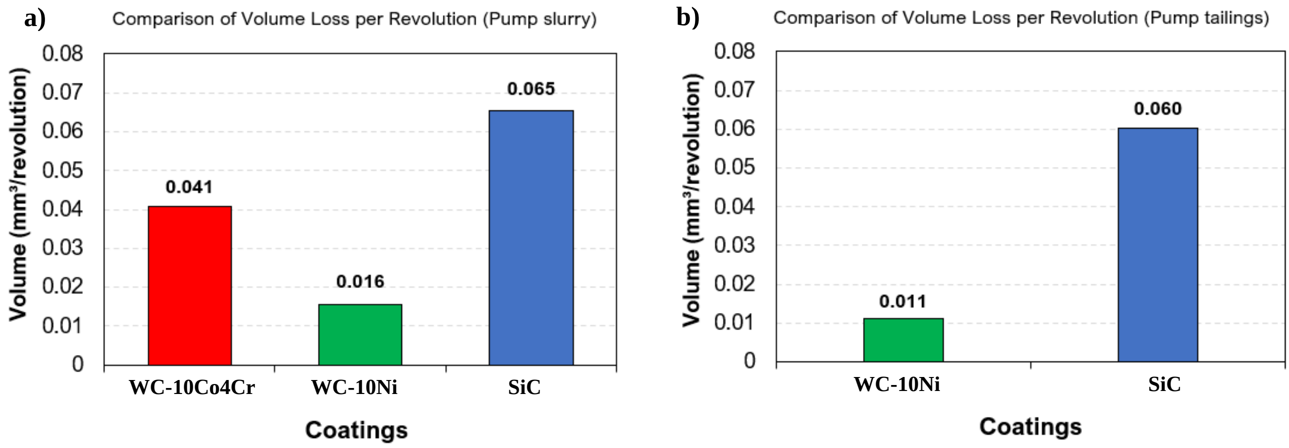

Figure 12. Comparison of the volume loss of the coatings of each rotor a) pump slurry b) pump tailings

The results in Figure 12a demonstrated that the suggested coatings had lower wear rates than SiC, being 76% lower with WC-10Ni and 38% lower with WC-10Co4Cr. Although it lost mass because of the holes that the AISI 304 weld filled, it should be noted that the WC-10Ni coating had the least wear. Comparing the performance results of the coatings owing to volume loss to the slurry pump rotor reveals that the WC-10Co4Cr coating would last 1.4 times longer and the WC-10Ni coating would last roughly 4.2 times as long. In the case of the tailings pump, the rotor coated with WC-10Ni would last 5.35 times longer than that coated with SiC, and its performance might be further enhanced if the coating on the surfaces of the blades was reinforced. In Peat's (2016) research, samples coated with WC-10Co4Cr saw a volume loss through erosion that was five times less. In these experiments, the WC-10Co4Cr coating did not achieve this degree of resistance, but the WC-10Ni coating came very nearby. According to Hutchings and Shipway (2017), the wear rate of a material is related to the geometry of the plastic deformation, of the component in operation, caused due to the impact of a hard particle on the material, which directly depends on the speed of impact, the shape, particle orientation and impact angle.

4. CONCLUSION

In this case study, ceramic coatings applied by the thermal spray technique—HVOF—were used to protect the surface of the slurry and tailings pump rotors from wear, and they were compared to a manually applied SiC coating. following results:

The AISI 316 stainless steel rotor wear mechanisms were identified and compared with the literature, although the process is the same, the slurry pumping from the literature is a little different. According to the analyses, abrasion and erosion are the main wear mechanisms. Erosive wear results in the highest volume loss since it locally damages the inner surface of the rotor where the slurry impact.

Due to an effective melting of the raw material during the thermal spraying process, the WC-10Co-4Cr and WC-10Ni coatings exhibited high uniformity of the deposited surface, dense microstructure, and low porosity. The best results with the WC-10Ni coating were obtained in the field test, however it is required to coat the rotor more, giving priority to the areas that are more worn. The coating thickness made of 0.2 mm made by HVOF was insufficient to contain the wear. For these pumps, the SiC coating is applied no less than 5 mm manually, with 12 times more coating volume as protection. Despite this difference, the WC-10Co4Cr coated slurry rotor would last 1.4 times longer, while the WC-10Ni would last about 4.2 times longer than the SiC. The WC-10Ni coated rotor would last 5.35 times more than the SiC-coated one.

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6. REFERENCES

ASTM G65-94, 1996, *Standard test method for measuring abrasion using the dry sandrrubber wheel apparatus*, ASTM International, Philadelphia, PA.

ASTM G99-05, 2016, *Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus*, ASTM International. Philadelphia, PA.

Bayer, R. J., 2004. *Mechanical Wear Fundamentals and Testing revised and expanded*. CRC Press.

Bauer, K. A. A., Castro, R. M., Curi, E. I. M., da Rosa, M. P. S., da Silva Rocha, A., Pereira, M., 2021. Análise de desempenho de superfícies revestidas com Cr3C2-25NiCr, WC-10Ni e WC-10Co4Cr depositados por aspersão térmica-HVOF aplicadas em rotores de bombas de polpa. *VI Congresso Brasileiro de Carvão Mineral – CBCM 2021*. Porto Alegre, Brazil.

Belém, M. J. X., Lima, C. R. C., Kuhl, A., Camargo, F., 2020. Avaliação da resistência ao desgaste erosivo e abrasivo de revestimentos WC-12Co aplicados por aspersão térmica HVOF. *Matéria (Rio de Janeiro), Vol. 25, pp. e-12583.*

Bergmann, C. P., Vicenzi, J., 2011. Protection against erosive wear using thermal sprayed cermet: a review. *In: Protection against Erosive Wear Using Thermal Sprayed Cermet.* Springer, Berlin, Heidelberg.

Bobzin, K., Zhao, L., Öte, M., Königstein, T., Steeger, M., 2018. Impact wear of an HVOF-sprayed Cr3C2-NiCr coating. *International Journal of Refractory Metals and Hard Materials*, Vol. 70, pp. 191-196.

Chauhan, A. K., Goel, D. B., Prakash, S., 2010. Erosive wear of a surface coated hydroturbine steel. *Bulletin of Materials Science*, Vol. 33, pp. 483-489.

DIN 50320. *Análise sistemática dos processos de desgaste. Classificação dos fenômenos de desgaste, Metalurgia e Materiais.* v. 53, pp. 619-622. 1997

Ferreira, J. A. B., 2016. *Estudo comparativo do desgaste erosivo–abrasivo de aços inoxidáveis e aços de baixo carbono*. Monografia do curso de Engenharia Automotiva, Universidade de Brasília, Faculdade UnB Gama, Brasília, Brasil.

Figueira Júnior, E. A., 2017. *Estudo e Concepção de Rotores de Disco para Bombeamento de Fluidos Abrasivos.* Tese de Doutorado, Programa de Pós Graduação em Engenharia Mecânica, Universidade Federal de Uberlândia, Uberlândia, Brasil.

Gerdau, 2021, Tabela de Composição Química. Gerdau Aços Especiais. São Paulo. https://www2.gerdau.com.br/sites/default/files/2020-10/Tabela_Composicao_Quimica.pdf. Accessed 20 Septemeber 2021.

Goyal, D. K., Singh, H., Kumar, H., Sahni, V., 2012. Slurry erosion behaviour of HVOF sprayed WC–10Co–4Cr and Al_2O_3+ $13TiO_2$ coatings on a turbine steel. *Wear*, Vol. 289, pp. 46-57.

Hutchings, I., Shipway, P., 2017. *Tribology: friction and wear of engineering materials*. 2nd edition. Butterworth-heinemann.

Lima, C. C., Trevisan, R., 2007. *Aspersão térmica: fundamentos e aplicações*. 2ª Edição. São Paulo. Artliber

Peat, T., Galloway, A., Toumpis, A., Harvey, D., Yang, W. H., 2016. Performance evaluation of HVOF deposited cermet coatings under dry and slurry erosion. *Surface and Coatings Technology*, Vol. 300, pp. 118-127.

Pukasiewicz, A. G. M., Oliveira, F. R. D., Capra, A. R., Paredes, R. S. C., 2012. Influência da refusão por plasma na microestrutura de um revestimento Fe-Mn-Cr-Si depositado por aspersão térmica arco elétrico sobre aço inoxidável ASTM A743-CA6NM. *Soldagem & Inspeção*, Vol. 17, pp. 65-75.

Thakur, L, Arora, N., 2013 A comparative study on slurry and dry erosion behaviour of HVOF sprayed WC–CoCr coatings. *Wear*. Vol. 303, Pp. 405-411.

Thapa, B., Upadhyay, P., Dahlhaug, O. G., Timsina, M., Basnet, R., 2008. HVOF coatings for erosion resistance of hydraulic turbines: Experience of Kaligandaki-A Hydropower Plant. *Water resources and renewable energy development in Asia*.

Voyer, J., Marple, B. R., 1999. Sliding wear behavior of high velocity oxy-fuel and high-power plasma spray-processed tungsten carbide-based cermet coatings. *Wear*, Vol. 225, pp. 135-145.

7. RESPONSIBILITY NOTICE

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