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Surface coating of stainless steels by HVOF method and investigation of wear properties

HVOF yöntemi ile paslanmaz çeliklerin yüzeylerin kaplanması ve aşınma özelliklerinin incelenmesi

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Abstract

The surfaces of 316L stainless steels, which are frequently used in the industry due to their mechanical properties, were coated with HVOF method in order to improve their properties. Two different powders for steel surfaces; Diamalloy 2002 (Tungsten Carbide, chromium based) and Metco 7202 (chromium based) powders were prepared in different concentrations. Group A specimens were coated with a mixture of 50% Diamalloy 2002 and 50% Sulzer Metco and Group B specimens were coated with a mixture of 100% Sulzer Metco 7202 by HVOF method. These powders produce coatings that provide wear resistance due to their content. The surface properties of the coated samples were analysed by some methods. Optical and SEM images of all samples were taken and XRD analyses were performed. The coating layer is clearly visible. Some porosity formation was observed. Microhardness values were measured. As a result of hardness measurements, it was determined that the surface hardness increased 4-7 times with the coating. Linear abrasion tests were performed with CSM abrasion tester. It was observed that the abrasion resistance increased. After the abrasion test, roughness measurements and SEM-EDS analyses of the abraded surfaces were performed. Abrasive and adhesive wear formations are present on the worn surfaces.

Keywords: HVOF, 316 stainless steel, Surface coating, Mechanic properties, Wear

Öz

Endüstride mekanik özellikleri sebebi ile sıklıkla kullanılan 316L paslanmaz çeliklerin yüzeyleri, özelliklerini iyileştirme amacıyla HVOF yöntemi kaplanmıştır. Çelik yüzeyleri için iki farklı toz; Diamalloy 2002 (Tungsten Karbür, krom esaslı) ve Metco 7202 (krom esaslı) tozları farklı konsantrasyonlarda hazırlanmıştır. A grup numuneler ; %50 Diamalloy 2002 ve %50 Sulzer Metco karışımı ile B grup numuneler ise %100 Sulzer Metco 7202 karışımı ile HVOF yöntemi yardımıyla kaplanmıştır. Bu tozlar içerikleri nedeni ile aşınma dayanımı kazandıran kaplamalar üretmektedirler. Kaplanmış numunelerin yüzey özellikleri bazı yöntemler ile analiz edilmiştir. Tüm numunelerin optik ve SEM görüntüleri alınmış ve XRD analizleri yapılmıştır. Kaplama tabakası net şekilde görülmektedir. Azda olsa bazı porozite oluşumları görülmüştür. Mikrosertlik değerleri ölçülmüştür. Sertlik ölçümleri sonucunda kaplama ile yüzey sertliğinin 5-7 kat arttığı belirlenmiştir. CSM aşınma test cihazı ile lineer aşınma testleri yapılmıştır. Aşınma dayanımlarının arttığı görülmüştür. Aşınma testi sonrası aşınan yüzeylerin pürüzlülük ölçümleri ve SEM-EDS analizleri yapılmıştır. Aşınan yüzeylerde abrasif ve adhesiv aşınma oluşumları mevcuttur.

Anahtar kelimeler: HVOF, 316L paslanmaz çelik, Yüzey kaplama, Mekanik özellikler, Aşınma

1 Introduction

Surface coating methods have become very popular and application areas have increased in recent years thanks to the financial, theoretical and technological benefits they provide [1-2]. The surface coating process aims to improve the surface of the material, improve its appearance, and make it resistant to the conditions in its environment as a result of precipitation of an element suitable for the material on the surface of the material. In surface technology, in some cases, obtaining the desired material is only possible thanks to coating technologies [2-6]. It is a surface coating method that aims to improve the surface of the coating material by examining its wear, corrosion and fatigue strength, to increase its advantages and to repair the materials in need of repair [7-13].

Thermal sprayed process is a demanding technique used for obtaining the coatings due to easy processability, reasonable material cost and good mechanical properties [9–15].

The coating can contribute to better hardness, excellent wear. These sprayed coatings consist of hard phase particles dispersed into the substrate material [16–19]. The coating material is first heated to molten or semi-molten state, then is injected to the substrate with a high speed, finally forming an coating area on the surface. The coating quality has a significant relationship with the sprayed parameters and deposited material properties [20–24]. Tungsten based powder is still the most popular and commercial composition by far. Chao Zheng et all have worked tribology's properties of HVOF coating. They have found e maximum

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microhardness of coating was about 1120 HV which has been increased about 3-fold of the substrate. The presence of hard phase was improvement of microhardness values. Geng Z. and friends found that tungsten-based coatings improve the wear resistance of the surface [20-21].

High velocity oxy-fuel (HVOF) improve the wear resistance and decrease the friction coefficient between various sliding components in automotive, aeronautical and space.

The high velocity oxy-fuel (HVOF) process can be used to achieve relatively low particle temperature and high speed (900 m/s). Thus, dense coatings with low porosity and less prone to oxidation can be obtained [10].

The HVOF sprayed WC-based cermet hard coatings such as WC–Co, WC–CoCr and others are applied in different engineering applications due to wear resistance and good corrosion resistance. Cobalt acts as a tough binder, which deforms plastically on impact onto the substrate and accommodates the wear-resistant WC particles [14].

Experimental studies were carried out after coating with HVOF and their findings were evaluated. Mixing 50% Diamalloy 2002 and 50% Sulzer Metco 7202 powders to A group samples, and 100% Sulzer Metco 7202 powder to B group samples using 316 stainless steel HVOF was applied to the steel base. Wear test was applied to surface.

2 Material and method

In this experimental study, AISI 316 L stainless steel was used as the substrate and HVOF coating method was applied on the selected steel samples.

The coatings were made on the surface of 316 stainless steel by using various powders by HVOF method. The surfaces were examined with a performed for elemental analysis in Table 1.

In the HVOF coating process, 316L stainless steel with dimensions of 100 x 100 x 4 mm was used as the substrate in this parameter. AISI 316 stainless steel has been sandblasted for this is to increase the efficiency of the coating to be made on the steel material.

The coatings were made on the surface of 316 stainless steel by using various powders by HVOF method percentages of powders to be coated are given in Table 2 and Table 3.

Two different powders were used in this study. The first powder is Diamalloy 2002 powder and the other powder is Sulzer Metco 7202 powder. The A samples are including; %50 Sulzer Metco Diamalloy 2002 powders (WC12Co) + %50 Sulzer Metco 7202(25NiCr-Cr3Cu2). In order to examine the effect of the number of passes in the experiments, different pass numbers were used. The parameters of the samples obtained with B group 100% Sulzer Metco powders are 1.5 bar nitrogen pressure, 2 cm length and 10 seconds time. The number of passes applied to these samples varies. The process parameters are given in Table 4. The changes in the surface properties as a result of the coating were investigated.

Table 1. Chemical analysis results of stainless steel

Steel Type	% Weight (wt%)							
	C	Mn	P	S	Si	Cr	Ni	Mo
AISI 316L	0.08 max 0.039	2.0 max 1.811	0.045 max 0.032	0.03 max 0.005	0.75 max 0.670	18 - max 16.539	11 - max 10.25	2.0 max 1.887

Table 2. Powders of HVOF process

Classification	Tungsten Carbide, Chrome Based (2002)	Carbide, Chrome Based (7202)
Chemical Structure	(WC 12Co) 33Ni9Cr3.5Fe2Si2B 0.5C	25NiCr-Cr3Cu2
Chemical Structure	Agglomeration	Agglomeration, Sintering
Morphology	Spherical	Spherical
Purpose	Abrasion resistance, corrosion resistance	Abrasion resistance, corrosion resistance
Particle size	+45, +11	-106, +45
Service temperatur	≤ 540°C	≤ 870°C
Apparent Density	2-2,5g/cm3	2.1-3 g/cm³

Table 3. The powder groups of HVOF coating process

	Powder -1 (A)	Powder-2 (B)
Chemical Composition	%50 Sulzer Metco Diamalloy 2002 powders ((WC12Co)33Ni9Cr3.5Fe2Si2B0.5 C) +%50 Sulzer Metco 7202(25NiCr-Cr3Cu2)	%100 Sulzer Metco 7202 powders (25Nicr-Cr3Cu2)
Grain Size	-45 +11 µm -106 +45 µm	-106 +45 µm

Table 4. Process parameters of HVOF treatment

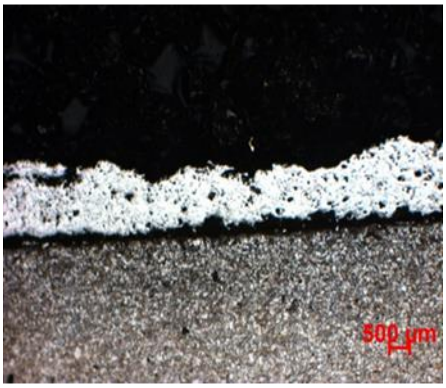
Samples	Passes	Parameters	
A1	**15**	**Shrouded**	**400 mm**
A2	**10**	**O2**	**150**
A3	**6**	**H2**	**300**
B1	**15**	**Gas**	**10 (H2)**
B2	**10**	**Disk**	**%15**
B3	**6**	**Speed (mm/sn)**	**300 mm/s**
		Spray Gun Distance	20 mm
		Passes	5

Coating thicknesses were measured and their effects on hardness and wear were examined. Before the wear test on the coating surfaces and optic images were taken. Coating structure was investigated with macro and micro-examined images. X-ray analyzes were made and the phases in the structure were determined.

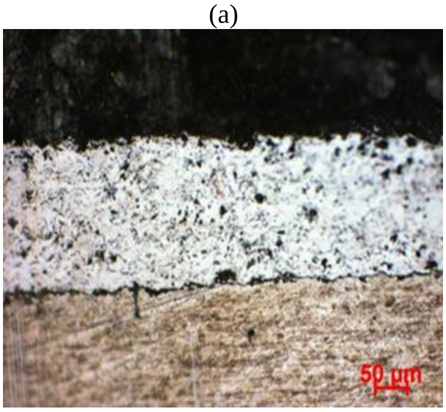
Surface roughness was checked, trace width after wear test the wear rates were determined by measuring the wear surfaces. Changes in surfaces according to images and EDS analyzes interpreted. Improving the wear properties with the coatings applied to the surface, wear tests were applied to the samples with different speeds, paths, loads and number of passes. The effects on the coating were investigated. SEM and EDS analyses were applied to worn surface.

3 Results

As can be seen from the coating images in Figure 1, there are occasional porosity formations. Powder particles, for which a small amount of melting cannot be efficient, are rarely seen. It can be said that the coating is successfully bonded to the sandblasted stainless steel surface. The sample with 15 passes is called A1, the sample with 10 passes is called A2, and the sample with 6 passes is called A3. The number of passes applied to these samples varies. The parameters of the samples obtained with B group 100% Sulzer Metco 7202 powder. The number of passes applied to these samples varies. The sample applied 15 passes was called B1, the sample applied 10 passes was called B2, and the sample applied 6 passes was called B3 sample. The passes were affected to thickness of coating layer. In the HVOF process, the amount of molten powder coming to the surface will increase with the increase in the number of passes, which causes the coating thickness to change. The variation of coating thicknesses according to the parameters is clearly seen in Figure 2.



(a)



(b)

Figure 1. Optical microscope image of the A1 and B1 group samples

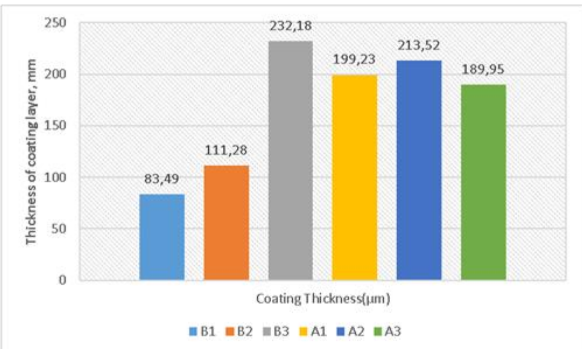
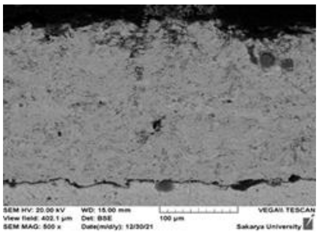


Figure 2. The coating thickness of coated sample by HVOF

Coating section of coated sample SEM images of A and B samples are given in Figure 3. When the coating images are analyzed, the presence of small amounts of porosity is seen from time to time. Due to the structure contained in HVOF coatings, porosities can be observed.



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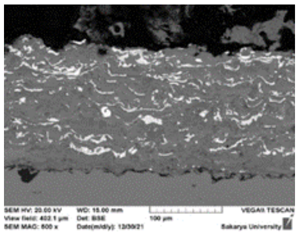
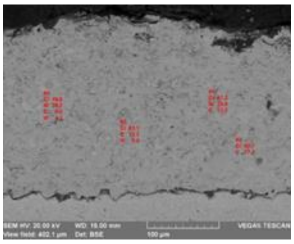
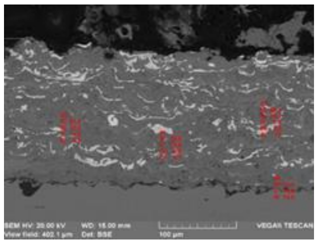


(b)

Figure 3. (a) SEM image of A3 sample, (b) B3



(a)



(b)

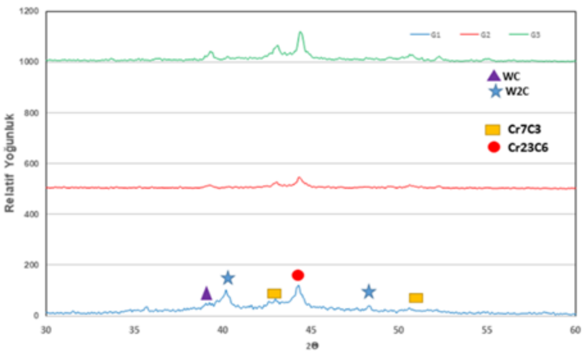
Figure 4. (a) EDS image of A3 sample, (b) B3

SEM image of A3 sample is given in Figure 3a. When we examine the A3 sample, it is clearly seen that the coating layer contains porosity. Adhesion is not very good. It cannot be said that the coating thickness is homogeneously distributed [15-18]. SEM image of B1 sample is given in Figure 3b. According to this image, it is seen that there is no good adhesion between the coating surface and its interface. Porous structures may have formed on the sample surface due to the preparations before coating. Since a good coating means a good interface, such results can be obtained when the surface preparation processes are not well prepared before coating [17-20].

EDS analyses of the A3 sample are given in Figure 4a. When these images are examined, it has been observed that the chromium element exists at different weights in different regions. In the image of the sample, the porosity is very low and a dense coating layer is seen. In the part marked with number 1, chromium element is more (47.2%) by weight. Nickel element was also observed in this region at a rate of 39.6% by weight. When we examine the 2nd and 3rd regions, 83.1% and 82.7% of the chromium elements are observed in these regions.

EDS analysis of B1 sample is given in Figure 4b. When looking at the image, it is understood that the distribution of Tungsten element is homogeneous. "W" element by weight (79.9%) was observed in the region marked with number 1. The other element with the highest weight is carbon. This marked and imaged region has a white structure. In the area marked with number 2, the element with the highest weight is chromium. Chromium penetrated the structure intensively in this region (67.5%). Nickel and carbon elements follow chromium in density. The region is dark in color. When we examine the region marked with number 3, it is observed that it is the region with the most elements. The highest element by weight is nickel with a ratio of 64.1%.

XRD analysis results of A and B samples taken from these coated surfaces are given in Figure 5.



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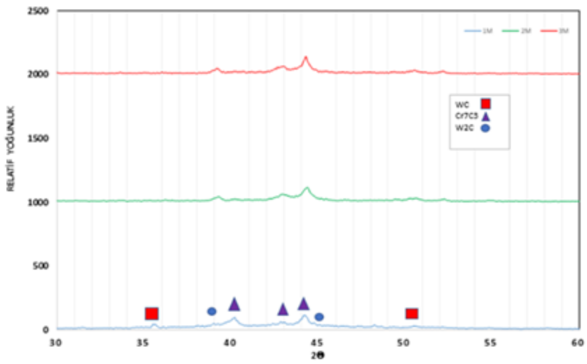


(b)

Figure 5. The XRD results of (a)A1-A2-A3 and (b) B1-B2-B3 Samples

When XRD analyzes of samples were examined, WC, W_2C, Cr_7C_3, $Cr_{23}C_6$ phases were found in A and B samples. $Cr_{23}C_6$ phase is also seen in M sample. When the A sample was examined, it was observed that the $Cr_{23}C_6$ phase was intense at the 45º 2θ angle. The presence of W_2C phases is observed at the angle of 40º and 48º. In the study of Zheng et al., the powders stored during the thermal spray process meet with oxygen at high temperature and cause chemical change [20,23]. The WC phase is available at an angle of 38º. When the G samples are examined, there are Cr7C3 phases at the angle of 40º-43º and 45º. It is seen that the WC peak intensity is intense at 35º and 50º angles. The formation of hard phase contents is present in both samples. Changes in these peak rates are important changes that can be a factor in mechanical properties.

The hardness values of the samples coated with the HVOF method and made with powder mixtures are given in Figure 6. The hardness values were taken from three different places with a microhardness device on the surfaces coated by using the thermal spray method, and the hardness values were recorded by calculating the averages of these values. When the samples are examined, hardness increases due to newly formed phases are observed. When the hardness values obtained after the coating process were compared with the hardness values obtained before coating, it was determined that the 5-7-fold coating process increased the hardness [20-22].

Chao Zheng et al. increased the hardness by a factor of 5 with HVOF, but in this study, the hardness increased more with parametric change [19,20].

Wuxi Zhou et al. also produced similar coatings and they were able to increase the hardness by 5-6 times. They also improved the mechanical properties, but the mechanical values are slightly higher in our study. this may be due to the advanced HVOF device and the high speed of the device, i.e. parametric [21,23].

Dense and hard phases formed on the surface significantly increased the hardness values. The hardness of the stainless steel used as a substrate in the coating process is 200 HV.

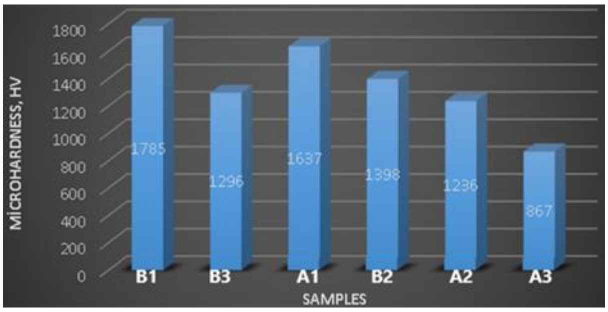


Figure 6. The Microhardness results of samples

Wear test results**;** In wear applications, 200 m distances were carried out at 0.4 m/s speeds, and the load was 3N and 5N. The parameters applied in the wear tests are shown in Table 5. After the wear tests, the wear track widths were examined with an optical microscope. Wear velocity strengths were calculated with the results. After the wear is done, the friction coefficients data are taken from the software in the wear device. Detailed explanation of samples test parameters is shown in Table 5.

Table 5. Parameters used in the wear process

Powders	1. Load (N)	2. Velocity (m/s)	3. Road (m)
A	3N-5N	0.4	200
B	3N-5N	0.4	200

In order to analyze the trace widths formed on the coating surfaces as a result of the tests obtained from the powder mixture A and the powder mixture B, different wear tests were carried out on the samples belonging to both groups. An experimental system was designed to examine the wear behavior of the materials coated with HVOF for velocity, load and path changes [21].

When the wear results of the samples obtained with the mixture of 50% Diamalloy 2002 + 50% Sulzer Metco 7202 powders are examined. The highest trace width is B sample group. It was detected at a speed of 0.4 cm/sec at 200 meters under a load of 1190 µm 3N. The highest trace width belonging to the A sample group belongs to the A1 (585 µm). The average of the trace widths of the A group samples was calculated as 475 µm. This value was recorded as 811 µm when the average of the B group samples was taken. It was observed at a distance of 200 meters under a 5N load and at a speed of 0.4 cm/sec. The lowest wear rate belongs to the A1 sample. It has been observed that the coefficient of friction increases when the number of passes at the same speed at the same distance is reduced [20-21].

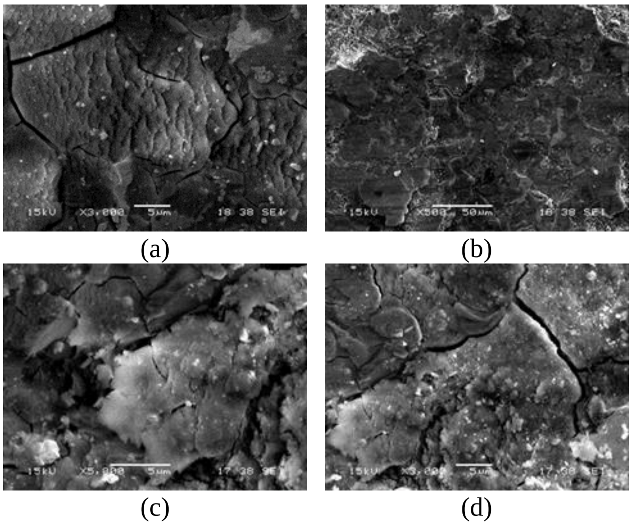


Figure 7. The SEM of worn surface of A samples after wear test. (a)A1 samples; 3N-0.4m/sn-200m, (b) A3 samples; 3N-0.4m/sn-200m, (c) A1 samples; 5N-0.4m/sn-200m, (d) A3 samples; 5N-0.4m/sn-200m

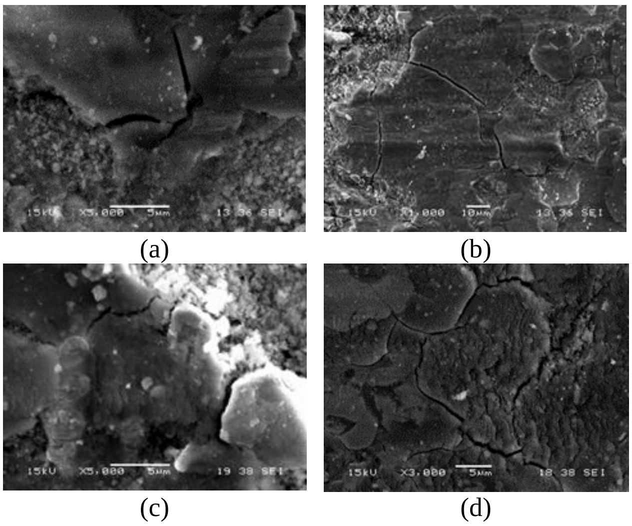
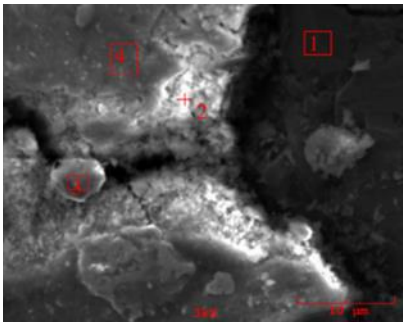


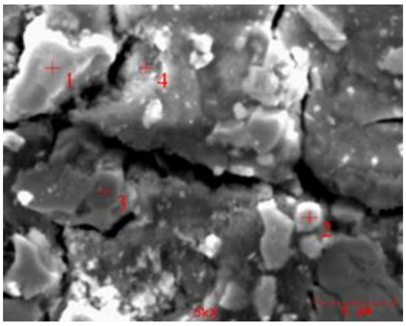
Figure 8. The SEM of worn surface of B1samples after wear test. (a) B1 samples; 3N-0.4m/sn-200m, (b) B1 samples; 3N-0.4m/sn-200m, (c) B1 samples; 5N-0.4m/sn-200m, (d) B3 samples; 5N-0.4m/sn-200m

When the SEM images of A and B group samples are examined (Figure 7-9) after the wear tests, the presence of porosity, crack formations, and surface ruptures are observed. The fact that this powder mixture is a little harder has made this situation common. In these samples, for which wear tests were carried out, when the load is increased, the depths of the cracks are observed, and when the distance to the road is increased, fatigue wear behaviors are observed in places. When coating is made from 100% pure powder, homogeneity is achieved and smoother surfaces are formed compared to mixed powder coatings [22-23].



Element, %wt	1	2	3	4
C	1.766	3.154	2.112	1.194
O	7.629	22.991	12.779	38.113
Al	0.134	2.083	0.481	2.095
Si	0.000	0.000	0.057	0.000
Cr	69.629	41.998	52.307	45.304
Co	0.291	0.279	0.719	0.344
Ni	19.257	10.107	29.170	10.848
W	1.294	20.389	2.375	2.101

Figure 9. The EDS analyses of A1 samples load 4N, velocity 0,4 m/sn, distance 200 m



Element, %wt	1	2	3	4
C	3.175	3.542	5.821	0.243
O	6.490	11.034	6.759	34.311
Al	0.086	0.182	0.008	0.987
Cr	56.405	67.056	80.703	47.667
Co	0.315	0.534	0.163	0.331
Ni	29.855	16.620	0.601	12.140
W	3.673	1.032	5.946	4.321

Figure 10. The EDS analyses of A1 samples load 4N, velocity 0,4 m/sn, distance 200 m

Figure 9 and Figure 10 gives us EDS analyses of A and B group samples after wear test. EDS analyzes taken from the surface after wear show wear products. Since the A and

B groups have different contents, different elements are seen in the EDS analyzes taken from the surface. The presence of Cr element was observed in the light colored region [23].

4 Conclusion

The different powders are used for HVOF coating such as the 50% Diamalloy 2002 and 50% Sulzer Metco 7202 powder. The process parameters were changed in coating process.

The coating thickness of A sample is measured as 213 µm. The layer thickness of B sample is 232 µm. The fact that the samples coated with the same parameters have different coating thicknesses can be associated with powder composition ratios. This is due to the difference in the structure and dimensions of the mixture powders and the homogeneous non-melting situation.

In some cases, it may also occur due to the device used in the experiment phase. WC, W_2C, Cr_7C_3, $Cr_{23}C_6$ phases were found in the X-ray analyzes of the samples after coating. $Cr_{23}C_6$ phase was also formed in 100% 7202 powder mixture. In both samples, the hard phase WC and W_2C phases emerged. These hard phases improved the mechanical properties (wear and hardness) of the coating surface. The hardness value increased approximately in the range of 5-8 times.

In a short time, the surfaces of the steels coated with the HVOF spraying method can be improved and used advantageously in industrial and economic pain. it was found that the number of passes and the wear rates were generally inversely proportional. Wear properties of B group samples better than A samples. In general, the abrasion resistance improved 2-3 times and the abrasion rate decreased.

The powders content is important for mechanical properties. The coating parameters are very important all surface properties.

The wear resistance of AISI 316 stainless steels, which were coated with the HVOF spraying method, was increased and their mechanical properties were improved.

Conflict of interest

This article is an original work. It was produced from the graduate study of a student named Batuhan Özer. Yıldız Yaralı Özbek provided consultancy and also took part in experimental studies. The article was prepared and edited by Yıldız Yaralı Özbek. There is no conflict between the authors.

Similarity rate (iThenticate): %13

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