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Wear Resistance and Brake Performance of Brake Discs Coated with Cr_3C_2-25%NiCr and WC-12%Co using the HVOF method

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Abstract

High Velocity Oxygen Fuel (HVOF) is one of the excellent approaches used to coat lamellar graphite cast irons with wear-resistant Cr_3C_2-25%NiCr Chromium Carbide-Nickel Chrome and WC-12%Co tungsten carbide with good qualities. In this research, -45 +5 µm Cr_3C_2-25%NiCr and WC-12%Co sintered powder is used to coat the surfaces of the brake discs, which are made of lamellar graphite cast iron, that contact with the pads. Performance of the discs, which are covered with these powders, in terms of wear and braking characteristics are studied. The microstructure of the Cr_3C_2-25%NiCr and WC-12%Co coating, which is applied by using the HVOF spraying method, is characterized at each step by scanning with electron microscopy. Braking performance and coated surface wear testing is performed with SAE J2430, TS 555 and TS 9076 brake-on-disk tester. Wear mass loss values are examined by applying different loads at the sliding distance. Test results show that the amount of wear of the coated sample is reduced in comparison to the uncoated sample. As a result of this study, the effects on the microstructure, mechanical properties and abrasive wear behaviour of coatings deposited by using the Cr_3C_2-25%NiCr and WC-12%Co powder and an ethane-fuelled, high-velocity oxygen-fuel spray process are revealed.

Keywords: Wear, HVOF, braking, coating

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1. Introduction

The application environments used in the coating technology may be made suitable for the characteristics of the coating applied. In order to achieve adequate resistance against wear, corrosion and friction, various materials such as ferrous and non-ferrous metals, intermetallic compounds, alloys, ceramics and cermets can be coated. WC-Co powders in stoichiometric ratios or in certain ratios depending on the atomic weight % of used powders are used in many applications in order to improve the surface characteristics of the material to be coated using the HVOF thermal spraying process [1]. Hard chromium film coating, which is applied on the surface of the ferrous materials in order to increase the corrosion and wear resistance of these materials, is widely used in the applications. However, these hexavalent chromium compounds used in the coating process inflict substantial damages on the operator and the environmental health. For this reason, the researchers are studying on alternative chromium coating methods. HVOF, which is one of the alternative candidates, is the method of application of cermet coatings on surfaces with the spraying method. HVOF is created as the oxygen and fuel mix gases (propane, propylene and hydrogen) reach supersonic speeds at high pressures and the coating powder is fed to the flame. HVOF maximizes the kinetic energy while minimizing the thermal energy input. Therefore, dense, low-porosity coatings with high adhesion strength are achieved [2]. Advanced ceramic materials are increasingly used in many industrial areas such as aircraft, automotive, energy and chemical industries. With regard to the structure of WC-12Co coating that is deposited on mild steel by high velocity oxy-fuel thermal spray process, it is reported that the coatings present better abrasion resistance compared with conventional coating [3]. The coating microstructure, mechanical properties, physical properties and relations with coating defects, such as inclusion and porosity, of these coatings that are applied with nano-structured WC-18Co thermal spraying on steel base materials using the HVOF method are investigated [4]. In addition, the microstructure and aqueous corrosion characteristics of the HVOF-sprayed coatings of the commonly used alloy with the inherent NiCrSiB fluxing are investigated in the studies for spraying applied on BS EN 10083-1 C40E carbon steel [5]. It is explained that the parameters of higher current intensity, longer spraying distance and lower pressure have an effect on the coating material's ability to adhere with the surface. The surface roughness is achieved by applying grit blasting on A36/1020 steel using different abrasives. Higher surface roughness and adhesion were achieved with grit blasting under these spraying parameters [6]. WC-Co thermally-sprayed coatings applied on AISI 1020 steel substrates are often used for their high hardness and resistance to abrasion wear [7]. The coatings applied by using the WC-Co system generally have a high hardness and wear resistance [8-9]. The iron-based (Fe) alloy coating applied on mild steel substrate by HVOF process has been used to produce better mechanical properties of the substrate materials [10]. The spray coated WC-17Co and WC-10Co-4Cr coating has been applied on AISI 4340 steel and a reduction has been reported in the axial fatigue strength of coated steel in comparison to base metal [11]. The microstructure of the coating surface properties depends on the stand-off distance and oxygen flow rates [12]. The wear tests were carried out in a pin-on-disc wear-testing machine, the pin being manufactured from the friction material usually used in light truck brake pads [13]. Thermal spraying has been applied to improve the tribological and mechanical properties of aluminium alloys and aluminium matrix composites and it was observed that the coefficient of friction (COF) under lubricated/dry conditions was 0.09/0.26 for CrC75–NiCr25 coated on aluminium alloy [1]. The NiCr coating also shows fine, uniform and layered microstructure and also sliding wear conditions, and the lubrication due to free carbon from the decomposition of carbides and metal oxide debris formed during the sliding results in a decrease of friction coefficients [14]. Due to its tendency to exhibit brittle cracking, the plasma-sprayed ceramic Cr203 coating can only be recommended for sliding wear conditions. The micro welds caused larger coating parts to be pulled out; this was observed in the Cr3C2–NiCr coating in particular [15]. The as-sprayed coating consists of primary carbides, chromium oxide and a mixture of amorphous and nanocrystal-structured binder phases [16]. The microstructure and micro abrasive wear performance of both the uncoated substrates and the coated substrates were characterized by opticular microscopy. The coating presented excellent wear resistance when subjected to the ball cratering test method [17]. The Cr3C2-NiCr cermet is extensively used for wear and corrosion-resistant applications. Coatings applied using the WC-Co system generally have a higher hardness and wear resistance; in addition, primary carbides, chromium oxide and a mixture of amorphous were identified on the coated surface [18, 19]. In the study carried out on grey cast iron in order to better validate the tribological factors between the coated and uncoated surfaces, the coating performance of the Cr3C2-NiCr coating, which is applied on grey cast iron by using the HVOF coating method by changing the % ratios, is investigated in terms of wear characteristics [10]. The goal of this study is to carry out a comparative study in order to better validate the tribological factors between the coated and uncoated samples and to evaluate the coating performance of Cr_3C_2-25%NiCr and WC-12%Co coating, which is applied on brake discs made of grey cast iron by using the HVOF coating method, in terms of wear characteristics and braking performance.

2. Test Study Results and Discussion

In the study carried out in accordance with the SAE J4230 test standards, the results of the three repetitive tests have been obtained for coated and non-coated discs and average results are calculated, and a test device was designed and manufactured. Fig. 1 shows schematic view of the brake tester used in this study.

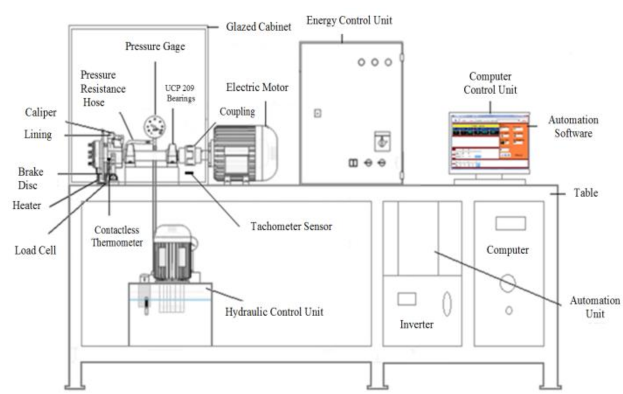

Fig. 1. Schematic configuration of the brake tester [23].

Surface roughness, dimensional thickness differences (with the help of a micrometer) and losses of mass (with precision scales) of the pad and discs to be tested are measured before and after the test. Specific wear rate is determined by the mass method following the Turkish Standard (TS 555) and British Standard (BS AU142) and calculated by the following equation:

$$V = \frac{(m_1 - m_2)}{L\ f_m \rho} \tag{1}$$

where, V is specific wear (mm^3/MJ), m_1 is mass of brake pad before testing (kg), m_2 is mass of brake pad after testing (kg), L is friction distance calculated by using the number of revolution and radius of the disc (m), f_m is average friction force (N), ρ is the density of brake pad (kg/mm^3) [20, 21, 25, 26].

A significant difference is not observed in the roughness value of coated discs measured before the test. Because here, the grain size of the powder used for coating and the cleaning methods applied to the surface after coating

are effective. The difference between the roughness values obtained after the test is due to the fact that the chemical characteristics of the powders are different and that there are no different, abrasion-resistant hard phases inside the coating created on the surface, which can also be observed in the XRD results. Cermet coatings provide a wide range of suitable solutions for solving the wear resistance. The performance of coated materials such as these is increased by protecting them from the environmental and physical effects in the area they operate. The coatings with WC-12%Co and Cr_3C_2-25%NiCr are coatings that are widely developed for gas turbines, steam turbines and aero-engineer in general. These types of coatings are developed for the sliding resistance, wear and corrosion resistance in general [22].
Automotive brake friction material was developed by using additive ulexite. The performance of ulexite on brake friction characteristics was especially examined. Friction materials investigated in this study were a non-asbestos organic (NAO) type material containing different ingredients including ulexite. It is obtained from Balıkesir, Bigadiç mine of Etibank in Turkey [23].
The roughness values of coated discs have increased after the test and they provided better adhesion with the pad during braking uncoated disk, it was measured that there is a decrease in the surface roughness and that the brake adhesion had a longer distance in parallel.

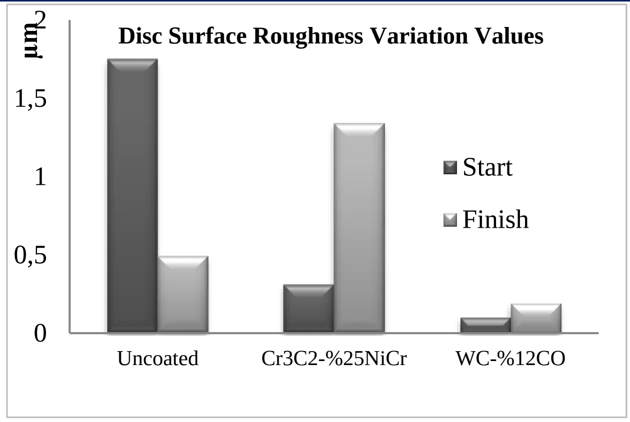

Fig. 2. Roughness variations that occurred on the discs.

These values are given in Figure 3. a, b and c. Surface roughness values obtained for the brake discs in test studies are given in Figure 2.
M. Shunmuga Priyan et al. used the Cr_3C_2NiCr powder mixtures using components with different percentages (%). In the study they carried out, they stated that the surface hardness increased around 3.5 times and that there was a decrease in the friction coefficient of coatings with a high carbide content [1].

Table 1 Thickness variations occurring on the brake discs during the braking performance measurements.

Thickness Variation Values for the Discs Measured during the Braking Performance							
Disc	Test Repetitions	1	2	3	4	Thickness Variation (mm)	Average Thickness (mm)
Uncoated Disc	Initial Thickness Value	24.6	24.6	24.6	24.6		0.22
	Test I	24.37	24.36	24.37	24.36	0.24	
	Test II	24.15	24.14	24.15	24.15	0.21	
	Test III	23.95	23.96	23.95	23.95	0.2	
Disc Coated with Cr3C2-25%NiCr	Initial Thickness Value	24.11	24.12	24.12	24.12		0.03
	Test I	24.08	24.09	24.09	24.08	0.04	
	Test II	24.04	24.05	24.05	24.04	0.04	
	Test III	24.03	24.04	24.04	24.03	0.01	
Disc Coated with WC-12%CO	Initial Thickness value	24.22	24.21	24.22	24.22		0.01
	Test I	24.2	24.19	24.2	24.19	0.015	
	Test II	24.19	24.18	24.19	24.18	0.005	
	Test III	24.18	24.17	24.18	24.17	0.005	

Table 2 Thickness variations occurring on the pad mounted on the brake discs during the braking performance measurements.

Pad Thickness Variation Values Measured during the Braking Performance				
Pad	Test Repetitions	Thickness (mm)	Thickness Difference (mm)	Average Thickness (mm)
Uncoated Disc	Thickness of the mounted pad I	10.54	5.12	4.21
	Thickness variation of pad I	5.42		
	Thickness of the mounted pad II	10.6	4.32	
	Thickness of the mounted pad II	6.28		
	Thickness of the mounted pad III	10.455	3.175	
	Thickness of the mounted pad III	7.28		
Disc Coated with Cr3C2-25%NiCr	Thickness of the mounted pad I	10.83	4.33	3.83
	Thickness variation of pad I	6.5		
	Thickness of the mounted pad II	11.43	4.73	
	Thickness of the mounted pad II	6.7		
	Thickness of the mounted pad III	10.59	2.43	
	Thickness of the mounted pad III	8.16		
Disc Coated with WC-12%CO	Thickness of the mounted pad I	10.36	2.87	2.59
	Thickness variation of pad I	7.49		
	Thickness of the mounted pad II	10.31	2.05	
	Thickness of the mounted pad II	8.26		
	Thickness of the mounted pad III	11.4	2.85	
	Thickness of the mounted pad III	8.55		

It has been determined that there is a decrease in the value of the frictional force generated after braking with time-dependent intervals in the uncoated brake disk. In the first braking with 200 repetitions, the frictional force value was measured as 0.78 while the frictional value at the last braking was measured as 0,34. As a result of these values, it is seen that the coefficient of friction is a reduction of about 2.3%. With this, during the experiments, the initial braking temperature was 108 °C, while the final braking temperature was 350 ° C. Using the HVOF method, Cr3C2-25% NiCr powder mixture was tested under the same conditions as the coating of the brake discs on the uncoated brake disc. In the first braking, the frictional force value was measured as 0,78 while the subsequent frictional force value was measured as 0,50. As a result of these values, it is seen that the value of the friction coefficient decreases by about 1,56%. During the experiments, however, it was observed that the temperature of the initial temperature was 107 °C and the highest temperature value was increased up to 327 °C as a result of repeated experiments. Figure 3-5 As seen in the topography image, even though the same linings are used, a rough surface arises from the coating material on the disc surface, which increases the grip on the braking stage. The other coating was made using WC-12% Co powder mixture. As with the other brake discs, the value of the friction force at the beginning was measured as 0,55 at 200 repetitive brakes, while the value of friction after the last braking was measured as 0,41. As a result of these values, it is seen that the value of the friction coefficient decreases by about 1,34%. However, at the beginning of the experiments the average temperature of the disinfection was 103 °C, and the highest temperature was found to rise to 334 °C at the end of the experiments. There are many ways to do this. The chemistry and structure of a friction layer depend on bulk materials (pads and discs), testing conditions and environment. The role of the friction layer may vary depending on its characteristics [23].

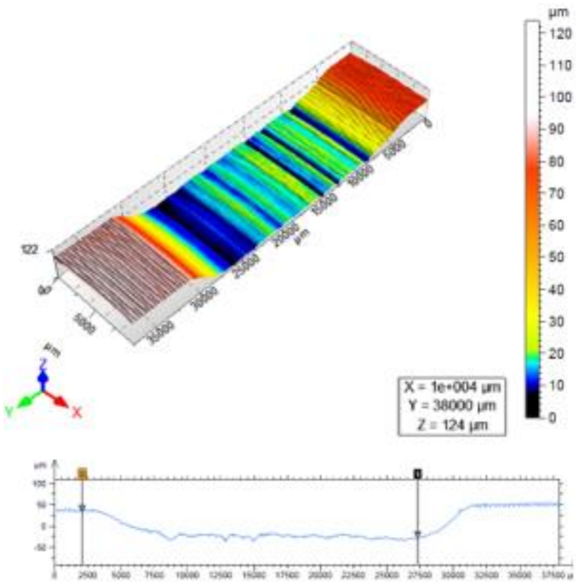

Fig. 3. Uncoated disc topography image

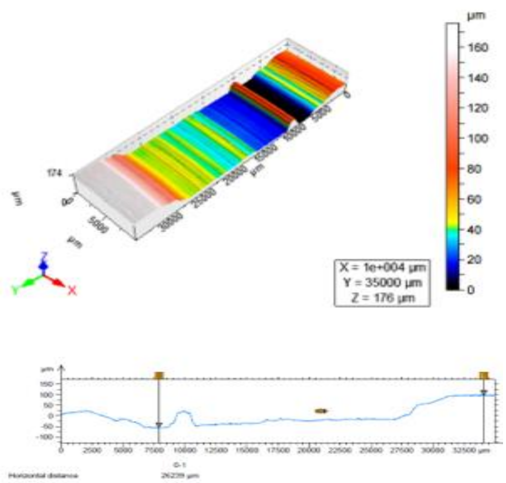

Fig. 4. Topography image of the disc coated with Cr_3C_2-25%NiCr

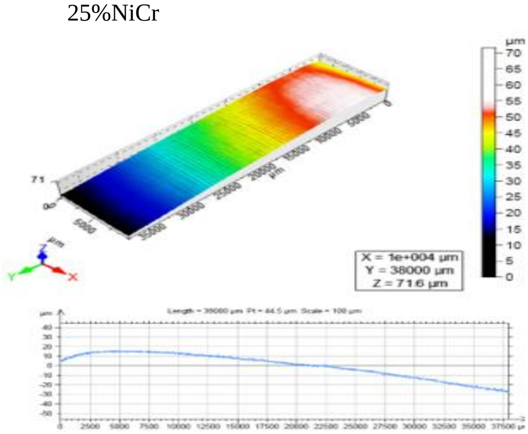

Fig. 5. Topography image of the disc coated with WC-12%Co

Ahmad Razimi Mat Lazim, Mohd Kameil Abdul Hamid and Abd Rahim Abu Bakar, conducted the friction test using chase type friction test with gray cast iron rotor to study the behavior of wear resistance and friction stability and tribological properties on the pad surface. Result showed that the manufacturing parameters of friction and wear play an important part and contribute to improve the tribological behavior of brake lining system [24, 25]. This work coated and uncoated investigates surface maping of the brake pads using energy dispersive X-ray analysis and EDX figure 6-9.

Table 3 Discs used in the test study

Material code	Name of the material: Brake disc with air channels, with a diameter of 280.00 mm
A	XRD patterns of the uncoated disc
B0	XRD patterns obtained from the non-worn section coated with WC-12%Co
B1	XRD patterns obtained from the worn section coated with WC-12%Co
C0	XRD patterns obtained from the non-worn section coated with Cr_3C_2-25%NiCr
C1	XRD patterns obtained from the worn section coated with Cr_3C_2-25%NiCr
D0	XRD patterns obtained from the non-worn section of the original disc
D1	XRD patterns obtained from the worn section of the original disc

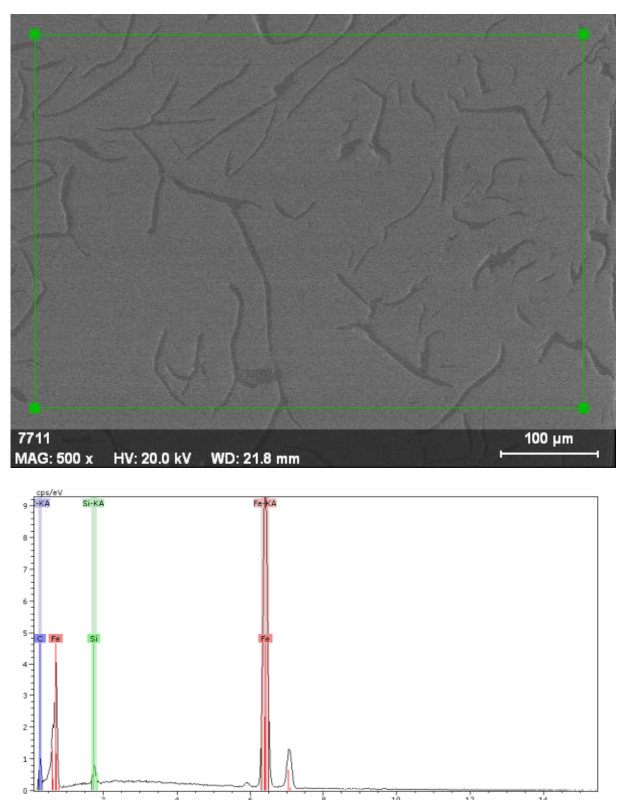

Fig. 6. SEM image of the Uncoated brake disc

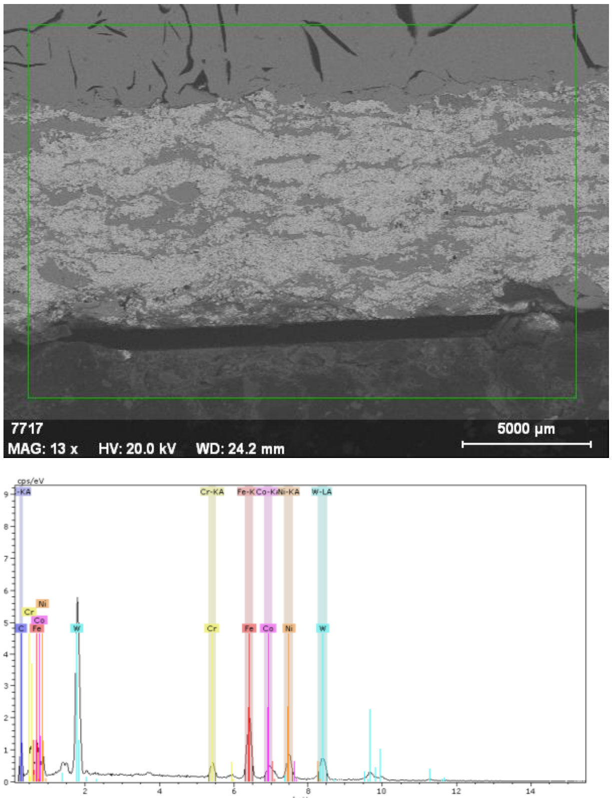

Fig. 7. SEM image of the disc coated with WC-12%Co

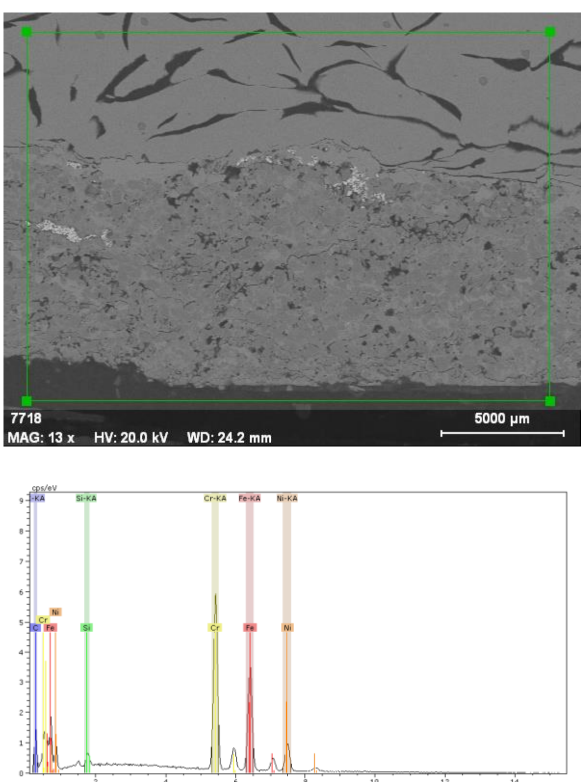

Fig. 8. SEM images of the disc coated with Cr_3C_2-25%NiCr

Numbered discs used in the test study are given in Table 3 and their XRD analyses are given in Figure 9.

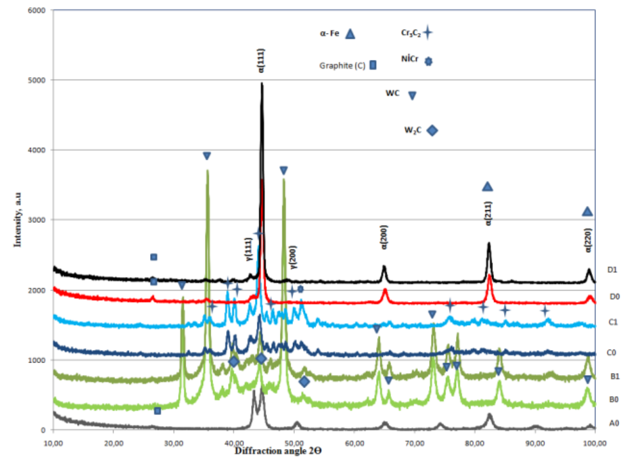

Fig. 9. XRD analyses of discs

4. Conclusions

In this study, brake disc surfaces made of cast iron are coated with Cr_3C_2-25%NiCr and WC-12%Co sintered powder using the HVOF technique. In the braking tests, it was observed that the decrease in the thickness of coated discs was very low. Similarly, the thickness of the pad used as the abrasive material decreased less in coated discs.

1. As the coating layer occurring on the brake disc surface decreases the friction coefficient when Cr_3C_2-%25NiCr coating is performed with HVOF, it can be used in these parts and moving parts where a similar wear could occur.
2. Where the pad thickness decrease was 4.21 mm in non-coated discs, the thickness decrease in discs coated with WC-12%Co sintered powder was determined to be 2.59 mm. Therefore, the pads may be used with a longer useful life with discs coated in this way.
3. The thickness decrease in brake discs is 0.22 mm in non-coated sample, whereas it is 0.03 mm in the disc coated with Cr_3C_2-25%NiCr and 0.01 mm in the disc coated with WC-12%Co. As the coated brake discs present less wear, they will be able to have a longer life on the car without being replaced.

3. Reference

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