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The effect of flame spray coating on the tribological properties of brake disc

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The Effect of Flame Spray Coating on the Tribological Properties of Brake Disc

Highlights

- *High bond strength was obtained between cast iron and NiCrBSi powder coated by flame spray technique.*
- *Hardness of coated sample was found to be approximately three times higher than that of cast iron sample.*
- *The wear rate of the coated sample was found to be lower than the wear rate that of the lamellar graphite cast iron.*
- *The surface roughness of the coated sample was seven times lower than that of the cast iron sample.*

Graphical Abstract

In this study, tribological properties of lamellar graphite cast iron disc surface, which are widely used in cars, were investigated. For this purpose the disc surface was covered with NiBCSi powder by the help of cost-effective flame spray coating technique.

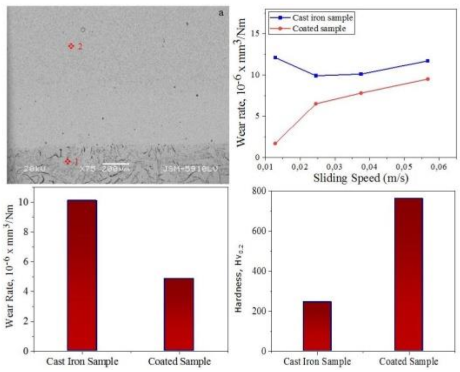

Figure. SEM micrograph (x200) taken from cross section of the disc coated with flame spraying and melting NiCrBSi, Wear rate change depending on sliding rate, Wear rate values under 10N load, Hardness values of cast iron sample and coated sample

Aim

The aim of this study is to improve the microstructure, wear, hardness and surface roughness of the brake disc coated with NiCrBSi powder coated with flame spray and melting method.

Design &Methodology

The characterization of and mechanical properties of NiCrBSi coated disc and uncoated disc were examined by SEM, EDS, profilometer, micro-hardness and ball on disc wear tests.

Originality

As Mentioned in the literature, surface modification with metal coating with ceramic powders can indeed improve the physical and tribological properties of brake discs. Inspired by this, the lamellar graphite cast iron-based brake disc surface has been modified with flame-spray coating NiCrBSi.

Findings

The coated disc showed superior properties than the uncoated disk in terms of surface roughness, hardness and wear resistance.

Conclusion

The coated sample produced higher hardness, lower surface roughness and less wear than the uncoated sample. This indicates a better tribological property and longer life coating sample.

Declaration of EthicalStandards

Theauthor(s) of thisarticledeclarethatthematerials and methodsused in thisstudy do not requireethicalcommitteepermission and/or legal-specialpermission.

The Effect of Flame Spray Coating on the Tribological Properties of Brake Disc

Araştırma Makalesi / Research Article

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ABSTRACT

The movement of moving devices or machines in terms of safety perspective must be controlled. In modern vehicle applications, braking is closely related to safety. Slowing or breaking the movements of vehicles safely is the task of braking mechanisms. The most important components of these mechanisms are the disc and brake lining pairs. Brake discs are made of lamella graphite cast iron. During the braking, the kinetic energy of the vehicle is converted into the heat energy through friction. The braking elements are subject to very heavy thermo mechanical conditions under heat, speed and load. The friction and wear properties of the brake disc must be thermally more stable against the heat energy generated on it in order to maintain stability. In this study, mechanical properties of the brake discs, which the disc surface was coated with flame spraying and melting, were improved. In addition, microstructure, abrasion, hardness and surface roughness tests of the brake disc were conducted. As a result, the coated disc showed superior mechanical properties compared to the original disc.

Keywords: Brake discs, coating methods, flame spraying, wear.

1. INTRODUCTION

In recent years, efforts have been made to reduce emissions and reduce fuel consumption by reducing the weight of vehicles in the automotive industry. Most engineering materials in use are expected to be light and have high performance. It is the task of braking mechanisms to slow or stop the movements of the vehicles under different operating conditions. The most important components of these mechanisms are the disc and lining pairs. Brake discs are made of graphite cast iron.

The friction of the brake pad against a cast iron disc has a great technological importance in the automotive industry. In addition, different physical rules of contact and friction mechanisms are involved in micro scale of braking. Friction motion is required and the coefficient of friction must be stable. The disc and lining pair must maintain its structure without being affected by temperature, humidity and the degree of wear, dirt and water splashes on the road. They also do not vibrate and make noise [1].

The surface properties of the brake disc exposed to high temperatures need to be improved. One of the most commonly used methods to solve the problems arising from friction and wear mechanisms is coating [2]. NiCrBSi coatings straighten the homogeneity by reducing porosities and improve micro structural properties and tribological performance. These coatings are widely used in large industrial applications where high temperature wear, friction, corrosion and oxidation are required [3]. Based on this information, Demir et al. [4] investigated the corrosion, friction and temperature-related brake attenuation characteristics by coating Al_2O_3-TiO_2 by plasma spray method and NiCr-Cr_3C_2 coating with HVOF method on the cast iron disc. Wang et al. [5] investigated the wear resistance and fatigue damage of the laser coating on wheel and rail materials. Wu et al. [6] investigated the microstructure and mechanical properties of 24CrNiMo dust on the brake disc by laser coating. Zamani et al. [7] studied the microstructure and mechanical properties of the material coated with Al_2O_3-Cr_2O_3 composite using plasma spraying. Poirier et al. [8] investigated corrosion, corrosion and thermal cycling resistance of aluminum-based disc surfaces by stainless steel coating using thermal spraying.

In our previous study [9], we investigated the temperature-dependent properties of wear, friction and braking performances by coating the brake disc with Cr_2O_3-40%TiO_2 by plasma spray method. The aim of this study was to investigate whether NiCrBSi (Metco 15E) ceramic powder coated with flame spray and melting method improves the braking performance of the vehicles and microstructure, wear, hardness and surface roughness of the coated surfaces.

2. EXPERIMENTAL PRODECURE

2.1 Material Preparation

In order to improve the performance characteristics of the cast iron brake disc shown in Figure 1, the surface of the

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disc was coated with NiCrBSi metallic-based composite powder by flame spraying and melting. Microstructure, abrasion, hardness and surface roughness tests were performed on the original and coated disc to determine the effect of the coating on the microstructure and mechanical properties of cast iron brake disc.

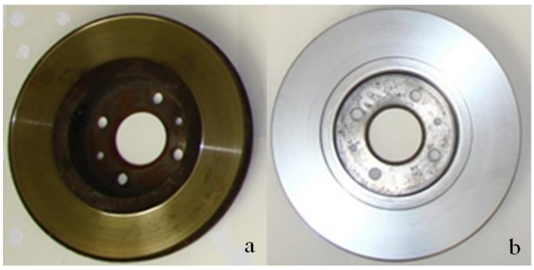


Figure 1. Views of the brake discs used in this study: a-cast iron sample; b-coated sample

The elemental composition of uncoated lamellar graphite cast iron sample and the coating material were analyzed with Thermo Niton Xl3t 980 brand spectrometer device, and the results are shown in Table 1.

Table 2. Coating parameters of NiCrBSi powder coated with flame spraying and melting method

Coating parameters	Specification/Value
Powder coater	NiCrBSi
Spray gun type	6 P
Spray nozzle type	MG-C 26
Spraying distance (mm)	50-75
Spraying angle	90°
Oxygen pressure (Bar)	4
Acetylene pressure (Bar)	0.7
Air pressure (Bar)	4.8-4.9
Oxygen flow velocity (m^3/s)	1.7
Acetylene flow velocity (m^3/s)	0.93-1.4
Spraying velocity (kg/s)	0.7-0.9

Table 1. Elemental composition of GGL sample and coating layer

The composition of elements (%)	**Fe**	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**	**Al**	**Cu**	**Ag**	**Ti**	**V**	**Mg**	**Zr**
The samples GGL	93.56	3.61	1.81	0.586	0.025	0.023	0.116	0.021	0.033	-	0.005	-	0.015	-	0.003	-
The coated material	3.59	-	-	-	-	-	54.69	-	0.047	0.018	0.148	0.047	40.88	0.328	-	0.015

2.2 Preparation of Disc Surfaces for Coating

In order to increase the adhesion strength between the coating and the backing material, the oxide film soil, grease, moisture, organic or inorganic substances on the surface of the substrate were cleaned and the surface to be coated was roughened. For this purpose, degreasing and sand blasting were carried out. After the sanding process, coating process was started. In the meantime, attention was paid not to waste much time to prevent the surfaces from becoming dirty again and not oxidized.

2.3. Application of Flame Spraying and Melting Coating Method

The cast iron discussed in the study was coated with NiCrBSi coating powder and the flame spraying with melting parameters given in Table 2 below. Table 3 presents the properties of flammable and burning gas used in flame generation.

Surface was cleaned from oil, rust and dirt. Sample discs were made by spraying with quartz abrasives at a pressure of 7 bar pressure in order to increase roughness of their surfaces. Since the connections between the sample disc and the coating layer had intermetallic phases and chemical properties, the coating process was immediately initiated to prevent the surfaces from being affected by atmospheric oxidation.

Table 3. Properties of oxygen and acetylene gas mixture [10].

Gas mixture	Flame temperature (°C)	Heat value (kJ/m^3)	Ignition speed (cm/s)	Flame yield (kJ/cm)
Oxygen-Acetylene	3300	56430	1350	45

2.4. Properties of NiCrBSi Powder

NiCrBSi is a metallic composite made of gas atomization method between 142 and 350 micro meter grain sizes by blending. Since it has good wetting properties, it provides excellent metallurgical bonding. It provides high hardness, abrasion and corrosion resistance as it can be obtained without porous and dense surfaces. The hardness value rises to 850-900 HV micro hardness [11].

NiCrBSi is alloy product made to improve the properties of conventional Ni-based alloys. Chromium improves oxidation resistance, high temperature corrosion resistance and hardness by providing a very good coating. The addition of boron and silicon provides the ability to produce better coatings by increasing the self-wetting ability of the NiCr alloy. The presence of carbon increases the hardness and abrasion resistance of the coating by providing carbide formation [12].

One of the most suitable methods in NiCrBSi coatings is the flame spray method. These coatings exhibit good wear behavior up to 500 °C and retain their volume [13]. Nickel-based coatings, in particular NiCrBSi coating, perform very well in corrosion and abrasion resistance applications at high temperatures. Ni-based alloys are known as spray-melting powders in thermal spray technology. The post melting process is carried out with the aid of an oxy-acetylene head or furnace between the solid-liquid temperatures (927-1127 °C) of the alloy. Thus, the diffusion and bond strength of the coating is increased between the coating layer and the base material [14]. Another way to increase the wear resistance of Ni-based alloys is the addition of hard phases such as WC, VC and CrC in the coating layer [15].

Nickel-based alloys used on their own or in combination exhibit superior properties such as high wear, corrosion resistance and high temperature resistance along with other reinforcing particles [16, 17, 18]. They are used in piston, cylinder, box packaging, sockets, pump shafts, food, medicine, automotive and aerospace industries. The effect of the load is higher than the temperature in the increase of wear in coatings made by NiCrBSi powder thermal spray method [13].

2.5. Mechanical Properties Testing

The microstructure, hardness, wear and surface roughness were measured as following: The samples were prepared by standard methods and the microstructures of the samples were examined with the Olympus BX-60 optical microscope (LM) and JEOL-JSM 5910-LV scanning electron microscope (SEM) and the micrographs of various sizes were taken and transferred to the computer. The microstructures of original and coated discs were examined by LM and SEM and analyzed by Oxford Industries Inca X-Sight 7274 energy dispersive spectrometer (EDS).

Using micro hardness device (Wolpert) with Vickers diamond pyramid tip and 200 g load, the measurements were conducted from 10 points and averaged. Wear tests were carried out in reciprocating wear test device under normal atmospheric conditions (at room temperature and 30% humidity). Using Al_2O_3 as abrasive ball, experiments were conducted under various loads (10N, 15N, 20N, and 25N) and various sliding speed (0.0128, 0.0245, 0.0375, and 0.0567 m/s); and the total sliding distance was 40 m. The measurements were made with surface roughness device (Mahr) which is perpendicular to the slip lines formed during rotation of the disc.

3. RESULTS AND DISCUSSION

3.1. Microstructure Features of Samples

The original disc and NiCrBSi coating prepared by standard metallographic methods were analyzed by using LM and SEM micrographs. Automobile brake discs are usually made of pearlitic laminated graphite cast iron [19]. X100 magnified light microscope images, which were polished by standard technique and showing graphite lamellae of cast iron brake disc that were branded using $5HNO_3$+95%CH_3OH, are shown in Figure 2.

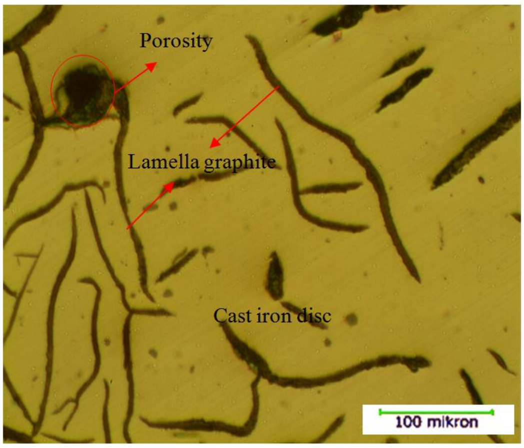


Figure 2. LM micrograph of the surface of the base material which is made of cast iron, x100

In Figure 3, a micrograph was obtained by x100 magnification from the surface section by light microscope. In micrograph, as a function of temperature and time, the presence of oxidized and carbide compounds has been observed due to the re-melting of the Ni element and the very small particle size distribution. NiCrBSi powder was used in flame spraying process and melting process was applied to improve mechanical properties. It has been observed that the Ni element settles more intensively near the boundary zone, thus providing a perfect mechanical bonding between the cast iron disc and the coating layer.

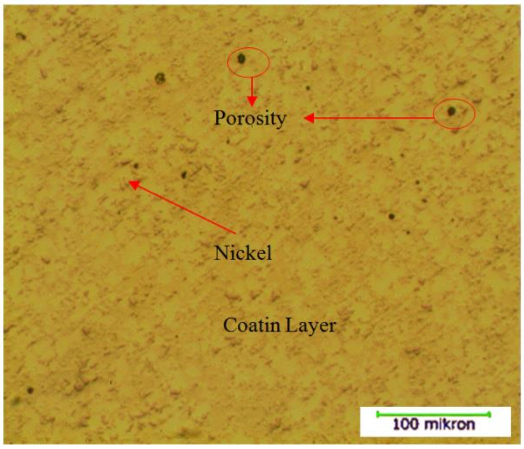


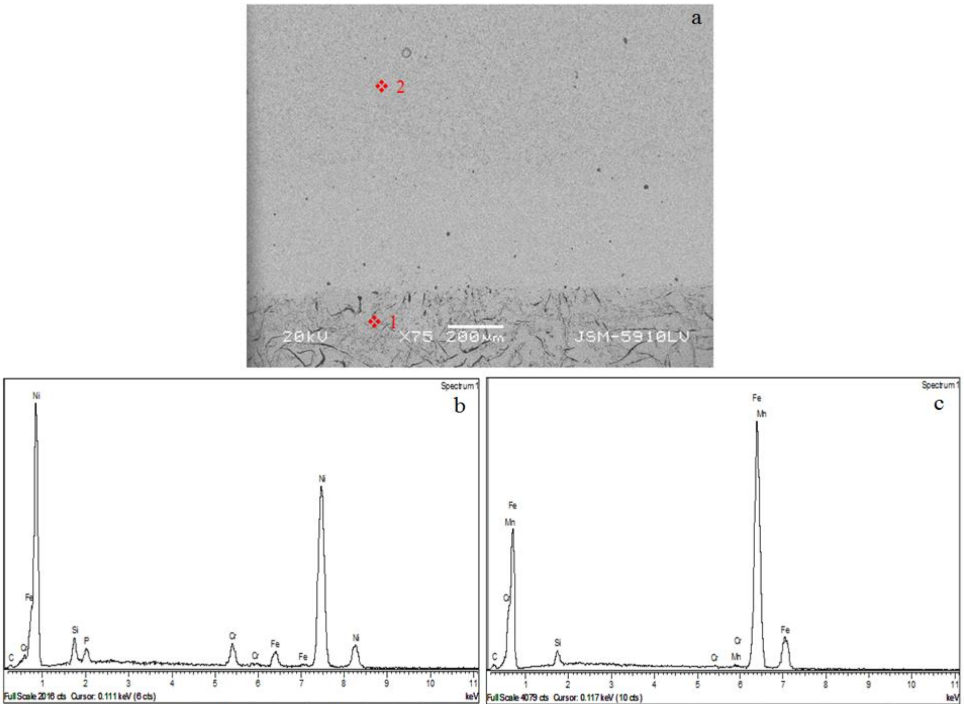
Figure 3. LM micrograph of the disc coated with flame spraying and melting NiCrBSi, x100

In Figure 4 (a), a small amount of ferrite in the perlite matrix seen in the region 1'of the SEM micrograph is a known structure. The graphite structures of the elemental free carbon atoms formed in the cast-iron matrix in different geometric forms can be seen. The EDS analysis of the samples taken from two different points indicated in this micrograph is shown in Figures 5 (b) and (c).

Based on the results of the analysis in Fig. 4 (b), the presence of Ni element in the region 2 of the SEM micrograph in Fig. 4 (a) is concentrated and also Fe, Cr, P, Si and C are available. The presence of oxidized and carbide compounds was determined in the melting of the Ni element, where the amount of Ni increased from the coating layer to the disc material.

In Fig. 4 (c), it is understood that the analysis of point 1 is typical cast iron disc material (> 90% by weight). The presence of C, Cr and Si elements in cast iron disc is understood from the analysis results.

In Figure 4 (a), the micrograph from the cross-section at x75 magnification shows that there is an excellent mechanical bond between substrate material and the coating. It is seen that there is a perfect bond between the cast iron disc and the coating layer. There are 1-2% pores in the coatings. It has been reported in previous studies that a certain amount of pores were present in thermal spray coatings [20, 21, 22].



Spectrum	C	Si	P	Cr	Fe	Ni	Total
Spectrum 1	3.95	3.69	1.97	4.40	4.02	81.97	100.00

Spectrum	C	Si	Cr	Mn	Fe	Total
Spectrum 1	5.83	2.07	0.46	0.77	90.87	100.00

Figure 4. SEM micrograph (x200) taken from cross section of the disc coated with flame spraying and melting NiCrBSi, and EDS analysis

In Figure 4 (c), the presence of Cr, Fe, P, Si and C elements in which the matrix was prominently Ni was determined in the analysis of point 2 on light gray. In the analysis, it is thought that Fe and C elements have been added to the structure by diffusion from the disc material. The presence of boron and silicon elements in the coating powder increased the ability of the NiCr alloy to self-wetting and provided the opportunity to produce better coatings [12]. It has been stated that the elements of boron and silicon reduce the melting temperature of the coating powder and increase the fluidity, thereby contributing to the formation of hard and oxidized hard phases. It is also reported that carbon increase the hardness and the abrasion resistance by providing hard carbides [23, 24, 25, 26, 27].

It can be seen in micrographs, nickel has perfectly bonded by re-melting and by showing interconnectivity with problematic disk material. This also supports the presence of elements such as Fe and C which are added to the structure by diffusion in EDS analysis. Oxidized compounds are likely to form in the coating layer as flame spraying and melting are in atmospheric conditions. SEM micrographs and EDS analyzes show that different morphological elements such as Fe, Cr, Si, C and P have distributed within the Nickel-prominent matrix. The oxide, carbide, porosity and the particles that are not fully melted indicate the discontinuity in the structure. This means a non-homogeneous structure. It is seen that the strong binding structure in SEM micrographs and light microscope images, has eliminates the disadvantages arising from this non-homogeneous structure disorder.

3.2. Wear Behavior of Samples

The wear test results of discs under 10 N load are given in Figure 5. The NiCrBSi coated disc showed a lower wear rate than the original disc. Wear tests were performed at different load and different shear rates to examine the effect of load and shear rate on wear.

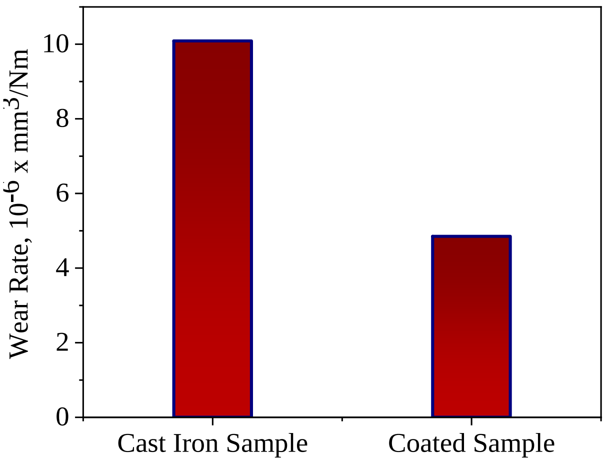


Figure 5. Wear rate values under 10N load

The change in the wear rate of the original disc-coated disc due to increased load and shear rate is given in Figure 6 and Figure 7, respectively. It has been observed that the wear rate of the NiCrBSi coated disc with high surface hardness is lower than the original disc in accordance with previous studies [28], while the wear rate of the coating in question has not been changed much due to the increased load (Figure 7).

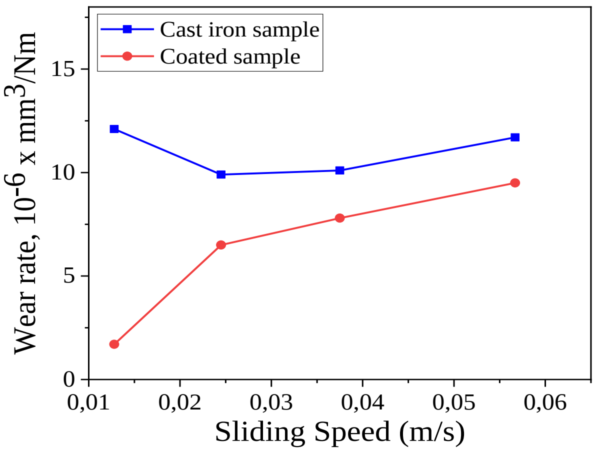


Figure 6. Wear rate change depending on sliding rate

The NiCrBSi coated disc with high surface hardness due to the increased shear rate shown a low wear rate compared to the original disc, it is shown in Figure 8 that there is no different change in wear rate.

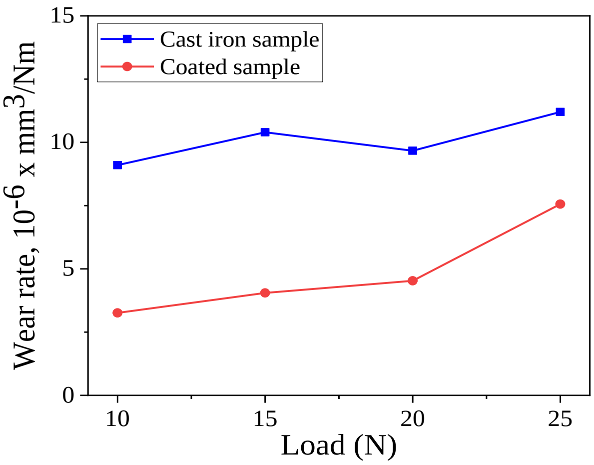


Figure 7. Wear rate change depending on loads

3.3 Hardness Behavior of samples

Micro hardness tests of original and coated discs were carried out by using Matsuzawa MHT-2 in TS 6503 EN ISO 4516 “Metallic and other inorganic coatings-vickers and knoop micro hardness tests”. The surfaces of the original and coated discs were applied at 200 grf for 15 sec, and the disc surfaces were divided into 36 degree distances and 10 measurements were made at equal intervals. The measured hardness values are given in Figure 8. The hardness of the cast iron disc is between 170-255 HB (~ 180-270 HV) [31]. The average value hardness of the original disc used in the study was measured as 245 $HV_{0.2}$. Depending on the coating parameters, the hardness of NiCrBSi coating in our study was 761 $HV_{0.2}$.

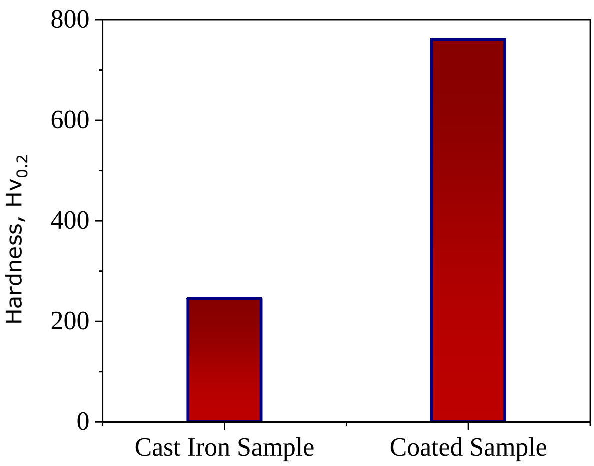


Figure 8. Hardness values of cast iron sample and coated sample

3.4. Surface Roughness Behavior of Samples

Generally, the average surface roughness value (Ra) of the new discs can be between 1.125-1.5µm [29]. Surface roughness values of the original and coated brake discs was measured 10 times, with the disc surface being marked with 10 equal parts - 36^0. The roughness values of the disc used in the experiment were determined by the obtained values.

Eriksson et al. (2002) reported that the disc structure has a significant effect on the friction coefficient not only in microstructure but also in terms of surface geometry. The decrease in the roughness values on the surface increases the friction coefficient by increasing the contact area [30]. The temperature resulting from the roughness of the surfaces during friction significantly affects the friction coefficient. The increase in temperature to a certain degree causes the friction coefficient to drop in the material and the system becomes inoperable [31]. The surface roughness values of the original and coated brake discs are shown in Figure 9 The surface roughness of the coated disc was found to be seven times lower compared to cast-iron sample.

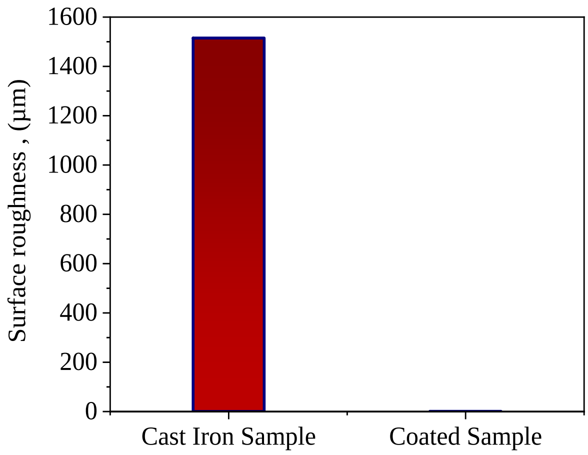


Figure 9. Surface roughness values of cast iron sample and coated sample

4. CONCLUSIONS

In this work, the flame sprayed NiCrBSi coating was re-melted by using the flame in an automatic mode. Microstructures and mechanical properties (such as hardness, bonding strength, wear performance and surface roughness) of the flame sprayed and re-melted NiCrBSi were systematically characterized. The results of this study are as follows:

1. The lamella structure, which is the characteristic of flame spraying coatings, occurred in the NiCrBSi coating. The coatings have a small porosity level. EDX analysis shows that diffusion is formed at the substrate/coating interface. In this case, the binding mechanism become metallurgical.

2. The re-melted NiCrBSi coating provides a lower wear volume than that of the cast iron sample at both 0.01 m/s and 0.06 m/s slide speed.

3. Micro hardness values measured on cast iron and coated sample surfaces, the hardness value of the sample coated with NiCrBSi powder was three times higher than the cast iron sample by flame spraying with melting. This was attributed to the formation of a more strong coating by the deposition of the nickel matrix coating powder in the W_2C coating layer during the re-melting process.

4. Due to the high hardness and hard carbide phases, the surface roughness value of the NiCrBSi coated sample was seven times lower than that of the cast iron sample. As a result, braking characteristics can thought to be better.

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