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INVESTIGATION OF THE COATINGS APPLIED ONTO BRAKE DISCS ON DISC-BRAKE PAD PAIR

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While braking, according to the severity of it, thermal, metallurgical, constructive and tribological occurrences emerge on the brake disc-pad interface. In this study, NiCr was sprayed as bonding layer onto the discs, one of which was coated with Al2O3-TiO2 by plasma spray and the other was coated with NiCr-Cr3C2 by High Velocity Oxygen Fuel (HVOF). In addition, the discs were tested with inertia dynamometer according to SAE's J2522 testing procedure. The measurements showed that although the pads of the coated discs were exposed to higher braking temperatures, friction coefficient of the disc coated with NiCr-Cr3C2 was obtained 6 % higher compared to the original disc.

Key words: coating, improving disc performance, Disc Thickness Variation (DTV), Brake Torque Variation (BTV)

Ispitivanje premaza primjenjenih na diskove kočnica na dva uloška za disk-kočnicu. Pri kočenju, zbog jačine, dolazi do termalnih, metalurških, konstruktivnih i triboloških pojava na sučelju uloška za disk kočnice. U ovoj analizi, na diskove je poprskan NiCr kao vezni sloj, od kojih je jedan disk premazan plazma sprejem Al_2O_3-TiO_2 a drugi je premazan s NiCr-Cr_3C_2 pod visokim kisikovim tlakom (VKT). Osim toga, diskovi su testirani dinamometrom inercije prema postupku testiranja SAE J2522. Mjerenja su pokazala da iako su ulošci premazanih diskova bili izloženi visokim temperaturama kočenja, dobiven je 6 % viši koeficijent trenja diska premazanog s NiCr-Cr_3C_2 u usporedbi s originalnim diskom.

Ključne riječi: premaz, poboljšanje učinka diska, odstupanje debljine diska (ODD), odstupanje zakretnog momenta kočnice (OZMK)

INTRODUCTION

In severe conditions, braking may cause the temperature on the disc-pad interface to rise up to 800 °C [1]. At such a temperature, the properties of organic compounds are disrupted, coefficient of friction (CoF) decreases, and the rate of wear increases exponentially. This phenomenon is called "fade" [2]. Ideal brake pads, without causing any fades, are expected to function in uniform and stable friction movement [3].

Thermal spray coatings, used to enhance thermal productivity of the systems, to increase the working temperature, and to improve corrosion, oxidization or wear behavior [4-5], provide a good engineering approach for surface compound characteristics [6-7]. Sanford and Jain [8] and Blau et al. [9] have extensively studied the coating powders that can be commercially used in the coating of brake discs. This study aims to identify the commercially viable hard coatings for discs and to determine their friction coefficient, wear, BTV and DTV characteristics. Two different coatings and coating methods have been selected for this purpose.

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EXPERIMENTAL PROCEDURE

Selection of coating materials and methods

In this study, three original front brake discs of a car were used. The chemical composition of one of the original discs was found to be 3,5C2,2Si0,5Mn0,02P0,03S as a result of the analysis using Spectrolab M5 Optical Emission Spectrometer. One of the other two discs was coated with NiCr matrix, having high resistance to abrasive wear and low CoF up to 850 °C and resistant to wear due to ceramic phase, and with NiCr-Cr_3C_2 to have resistance to corrosion [10]. NiCr (25 %)-Cr_3C_2 (75 %) coating powder was applied as 300 μm thickness onto the bonding layer of 45 μm thickness on both sides of the disc by HVOF method. The other disc was coated with Al_2O_3 - TiO_2, used in certain applications where resistance to abrasive, corrosive, oxidizing and erosive effects is required [11]. Primarily NiCr bonding layer of 30 μm was coated as the substrate through plasma spray and then the coating powder Al_2O_3-TiO_2 of approximately 500 μm was deposited onto the substrate.

Sample preparation

The cast iron discs were grit blasted, prior to depositing the coating, with silicon carbide to break the oxide layer and pre-roughen the metallic surfaces for improved adhesion. The discs were then cleaned by rinsing with trichloroethane and stored in an airtight container to retard oxidation of the freshly exposed metal. The coating material cools rapidly upon contact with the substrate and subsequent molten metal impacts to build up the coating to the required thickness. All the samples were examined according to standard metallographic procedure.

Electron microscopy of powders and coatings

Scanning electron microscopy was used to capture the images of the feedstock powder morphologies. The coated discs were sectioned perpendicular to the flat surface and the coating microstructures were analyzed using Jeol JSM-5910 LV type SEM device. Hardness measurements on the coated discs were conducted using Matsuzawa MHT-2 microhardness tester.

Wear measuring

The amount of wear on the discs and brake pads was identified through measurements of thickness and mass. The measurements were made before and after the tests. As seen in Figure 1, the dimensional wear was done on the four different points with 90-degree angles on the disc and on eight points on the brake pad. For weighing, EP-20KA scale, which can weigh maximum 20 kilograms and has ± 0,1 gram sensitivity, was used. To measure disc thickness, an electronic micrometer (Mitutoyo 293) of 0,3 μm flatness and 0,001 mm sensitivity was used.

Inertia-dynamometer test procedure

This SAE Recommended Practice defines an inertia-dynamometer test procedure to assess the effectiveness behavior of a friction material with regard to pressure, temperature and speed for motor vehicles fitted with hydraulic brake actuation [12]. Original (sized ∅255×22 mm) and coated discs were tested according to SAE J2522 Dynamometer Global Brake Effectiveness and Evaluation test procedure. In the tests conducted in this study only four test phases were employed (Table 1).

Figure 1. Wear measurement positions after testing the original disc

DTV measuring

In measurement of Disc Thickness Variation (DTV), six Capacitec brand, 4008-P115 model, three channeled capacitive props with 0,0002 expanded uncertainty ratio were used. The distance between the probe and the disc face was initially set to 1000 microns on the inboard face of the disc, and 2000 microns on the outboard face of the disc. Measurements were investigated in 1st fade test procedure.

RESULTS AND DISCUSSIONS

Materials and coating properties

Microstructural examination was done through SEM and thus micrographs. With the Energy Dispersive Spectrometer (EDS) unit on SEM, point analyses were made on the regions 1, 2, and 3 shown in Figure 2. As seen in the region 1 in Figure 2 (cermet coating with NiCr-Cr_3C_2), the long and flattened lamellar grains are in the same direction as the surface of the coating. In addition, the coating has a dense structure with visible but tiny pores (Figure 2-3). The EDS analyses of regions 1, 2, and 3 of the micrograph in Figure 2 are shown in Figures 4, 5, and 6.

The microstructure analyses of the Al_2O_3-TiO_2 ceramic coating on the cross-section and surface were performed with SEM and then they were analyzed with EDS unit (Figures 7-9).

Table 1. **Selected phases of SAE J2522 test standard**

Section	Number of Snubs	Braking-Release Speed / kph	Control	Initial Brake Temperature / °C
Green Effectiveness	30	80-30	30 bar	100
Speed/Pressure Sensitivity	8	120-80	10, 20, ...80 bar	100
1st fade (maximum 160 bar)	13	100-<5	0,4 g	100-500
Increasing Temperature Sensitivity (500 - 300 °C)	9	80-30	30 bar	100, 150, …500

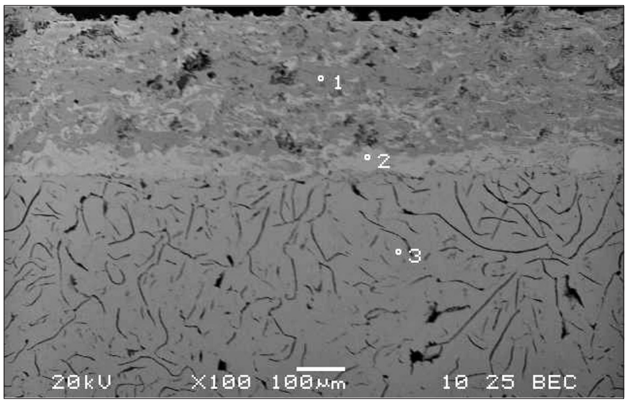


Figure 2. The SEM micrograph and regions of EDS analyses of the cross-section coated by HVOF, (1) $NiCr-Cr_3C_2$ coating, (2) NiCr bonding layer, (3) Grey cast iron substrate

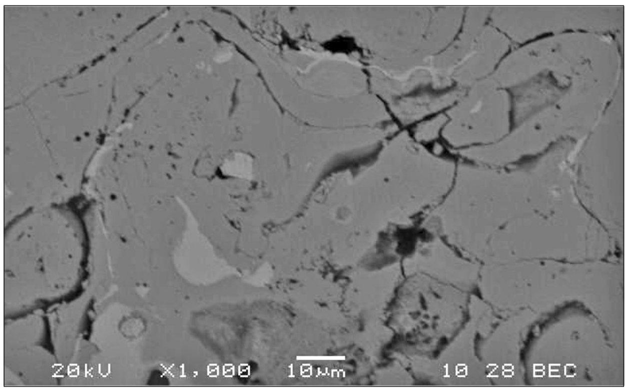
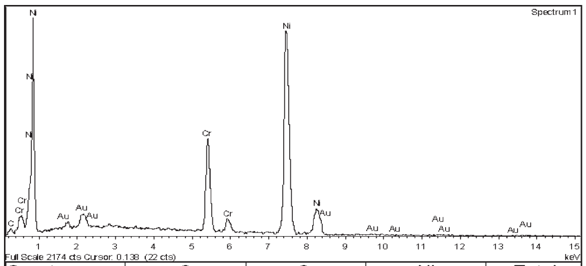
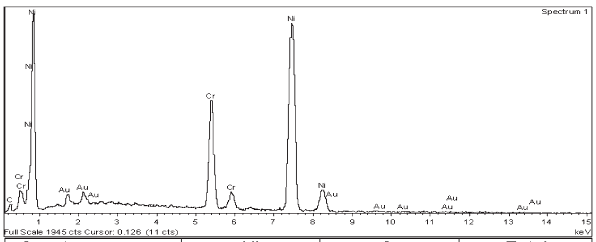


Figure 3. The SEM micrograph of the $NiCr-Cr_3C_2$ coated deposited by HVOF



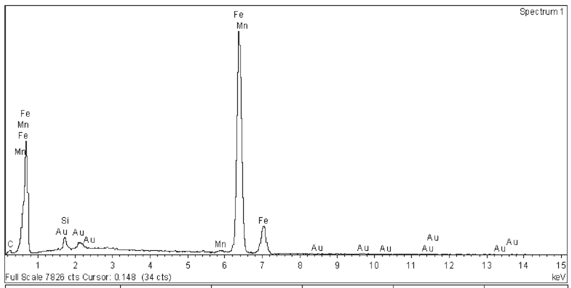
Spectrum	C	Cr	Ni	Total
Spectrum 1	4.34	16.32	79.35	100.00
Max.	4.34	16.32	79.35	
Min.	4.34	16.32	79.35	

Figure 4. The EDS analysis taken from the polished surface of the $NiCr-Cr_3C_2$



Spectrum	Ni	Cr	Total
Spectrum 1	70.00	30	100.00
Max.	77.00	37	100.00
Min.	63.00	23	100.00

Figure 5. The EDS analysis taken from the center of NiCr bonding layer of the polished cross-section coated by HVOF



Spectrum	C	Si	Mn	Fe	Total
Spectrum 1	3.65	1.83	0.52	94.00	100.00
Max.	3.65	1.83	0.52	94.00	
Min.	3.65	1.83	0.52	94.00	

Figure 6. The EDS analysis of grey cast iron substrate material

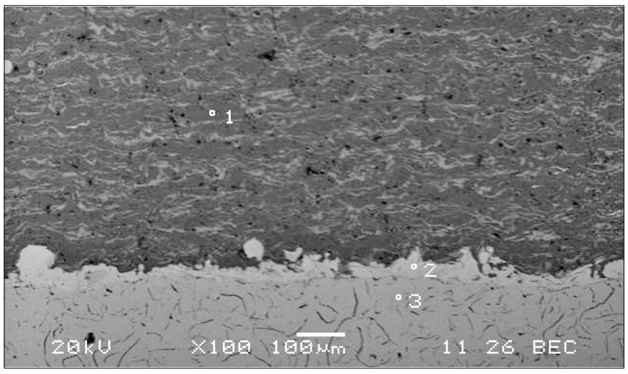


Figure 7. SEM micrograph of the cross-section of the Al_2O_3 -TiO_2 ceramic coating and NiCr bonding layer deposited on grey cast iron through plasma spray

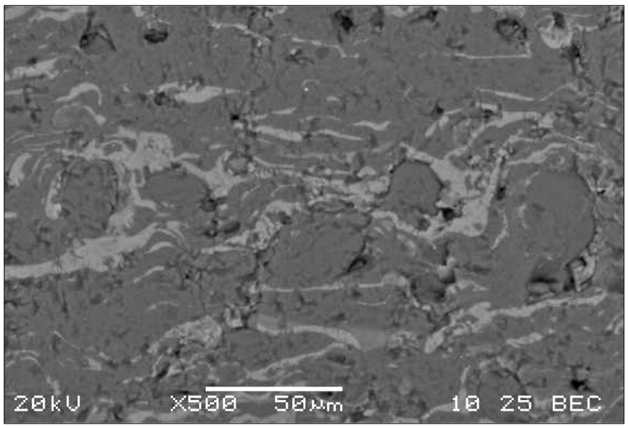
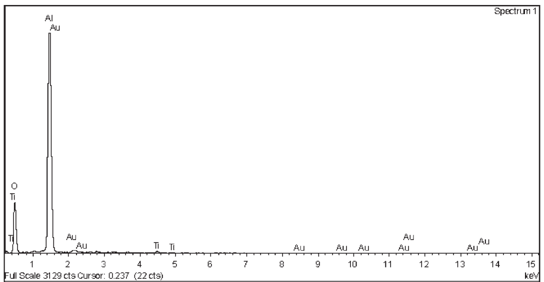


Figure 8. SEM micrograph of the polished surface of the Al_2O_3 -TiO_2 ceramic coating made by plasma spray



Spectrum	O	Al	Ti	Total
Spectrum 1	45.59	53.56	0.86	100.00
Max.	45.59	53.56	0.86	
Min.	45.59	53.56	0.86	

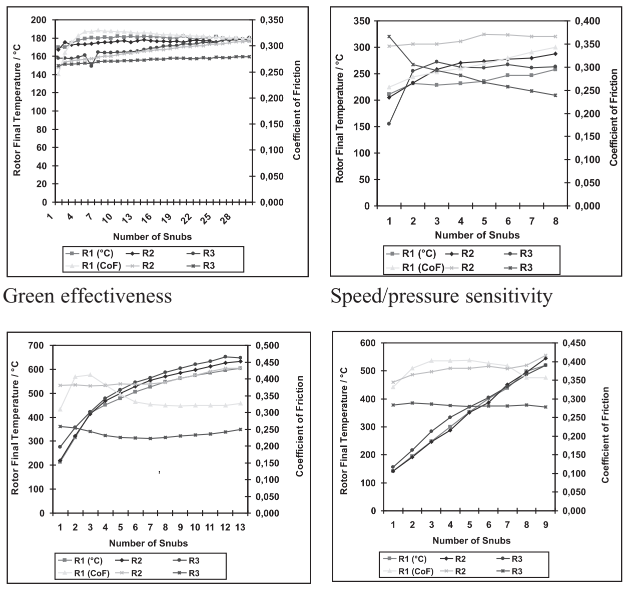
Figure 9. EDS analysis on the surface of the Al_2O_3-TiO_2 ceramic coating made by plasma spray

The obtained coatings exhibit a high morphological and microstructural anisotropy as shown in Figure 7. The top view reveals a significant segmentation of the coating due to large solidification rates when the splats built up. In addition, the cross section and surface view (Figures 7-8) shows a certain amount of unmolten particles which adhere weakly to the coating and represent the source of wrenching observed when polishing the samples. The coating has a dense structure with visible but tiny pores.

By Vickers hardness measurement technique, under 200-gram load, the average hardness of the NiCr-Cr_3C_2 cermet and was determined as HV0,2=766±25 as a result of eight measurements and as HV0,2=643±25 as a result of ten measurements, respectively.

Variation in coefficient of friction (CoF) with disc temperature

In the tests, the temperature on the discs, excluding the original disc, was measured by rubbing thermocouple. Additionally, both starting and finishing temperatures of the internal and external pads were measured. As shown in Figure 10, while the average CoF of the original disc (R1) and pads was 0,317, that of the disc coated with NiCr-Cr_3C_2 (R2) was 0,290 and that of the disc coated with Al_2O_3-TiO_2 (R3) was 0,273. However, at the speed/pressure sensitivity (120 km/h) stage, CoF values were recorded as 0,303, 0,359 and 0,282, respectively. R2 and its pads exhibited a perfect performance. Although R2 was exposed to a higher working temperature (up to 288 °C) than the other discs, its pads exhibited a stable friction behavior. In the other procedures, R2 and its pads continued to show high performance. At the first fade stage, it reached an average value of 0,397 CoF and at the increasing temperature sensitivity stage it reached a value of 0,380 CoF. At the first fade stage, the thermal barrier effect of the disc coated with Al_2O_3-TiO_2 ceramic caused the temperature of the pads working with the disc to go up approximately to 700 °C.



Green effectiveness

Speed/pressure sensitivity

1st fade

Temperature sensitivity

Figure 10. Final temperature of the discs and variation in CoF

However, despite such a high temperature, it was interesting to find that the pads maintained their friction behavior almost the same as it was at the beginning and that they were stable. However, as the temperature was extremely high, the number of braking at this point was kept as 13. During first fade procedure, the temperatures forming on the discs approximated to each other. At the increasing temperature stage, both the disc-pad pairs of R1 and R2 had an average CoF value of 0,380. At this stage, the disc R3, having 0,283 as CoF at the beginning, moved slightly away from this value reaching 0,278.

Wear testing

R3 completed the tests without wear. However the amount of wear increased on pads due to the hardness of the coating, thermal barrier effect, and high operating temperatures (Figure 11). Wear in R2 was seen more than R1 because of high running temperature, high CoF and non-uniform rotating geometry. However, considering all the tests, the R2 disc-brake pad pair yielded competitive results.

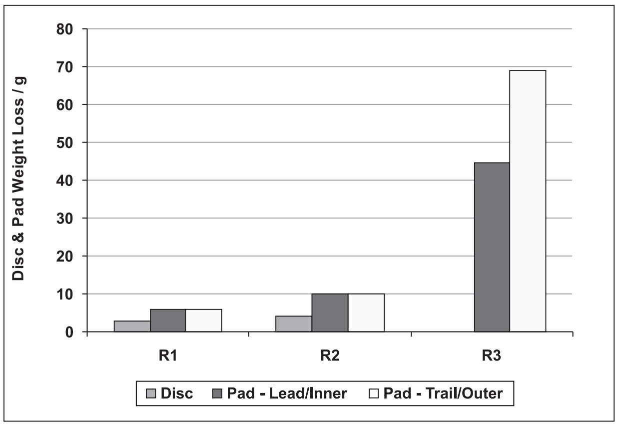


Figure 11. Mass wear on discs and pads

Brake Torque Variation (BTV)

Factors such as geometrical irregularities, unsteady wear, layer of friction and heating, friction properties, level of friction, and external forces trigger BTV. The mechanical effects leading to BTV depend not only on manufacturing tolerances but also on tribological issues. Because of high temperature gradients and unsteady thermal expansion of the disc material, temporary DTV may emerge [13].

In disc brakes, there exists a linear relationship between brake torque and the CoF of the brake-pad [14]. For example, a 10 % increase in the CoF increases the brake torque by 10 %. As the BTV graphics of the discs

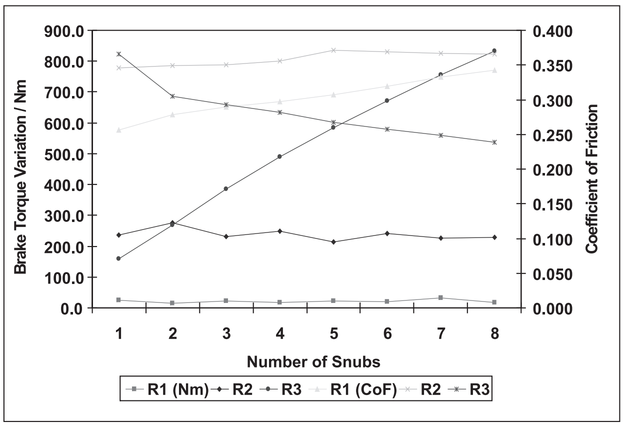


Figure 12. Examination of BTV in speed / pressure sensitivity (120-80 km/h) test procedure

are shown in Figure 12, the results, excluding those results regarding R3, roughly support this explanation.

Disc Thickness Variation (DTV)

DTV is one of the recognized mechanical constituents of brake torque variation [15] and generally is caused by the unsteady wear of the disc [16]. As seen in Figure 13, there is a high deviation in the DTV of R3. This deviation was influenced by the variations in pad temperatures and by the pads being exposed to adhesive wear in high temperatures. It is thought that the particles coming off the pads were stuck on a point where there was a maximum temperature on the disc-pad interface. In the proceeding braking, because the particles coming towards the disc surface through adhesion could not firmly attach to the disc surface, they left the disc surface, throwing up to the environment. Though slight, this was influential in the thermal expansion as a result of the high temperatures on DTV values.

CONCLUSIONS

– In the four test procedures covered in this study, it was identified that the pads of the R2 and R3 (the coated discs) were exposed to higher braking temperatures. Despite this, it was observed that the CoF of R2 increased by 6 % compared to that of the R1 (original disc). Therefore, it can be stated that if R2 is used in vehicles, there may be an increase in active safety.

– R3 proved to be superior as it did not wear. However, its pads were exposed to high working temperatures due to the disc's thermal barrier effect. Consequently, there occurred a noticeable amount

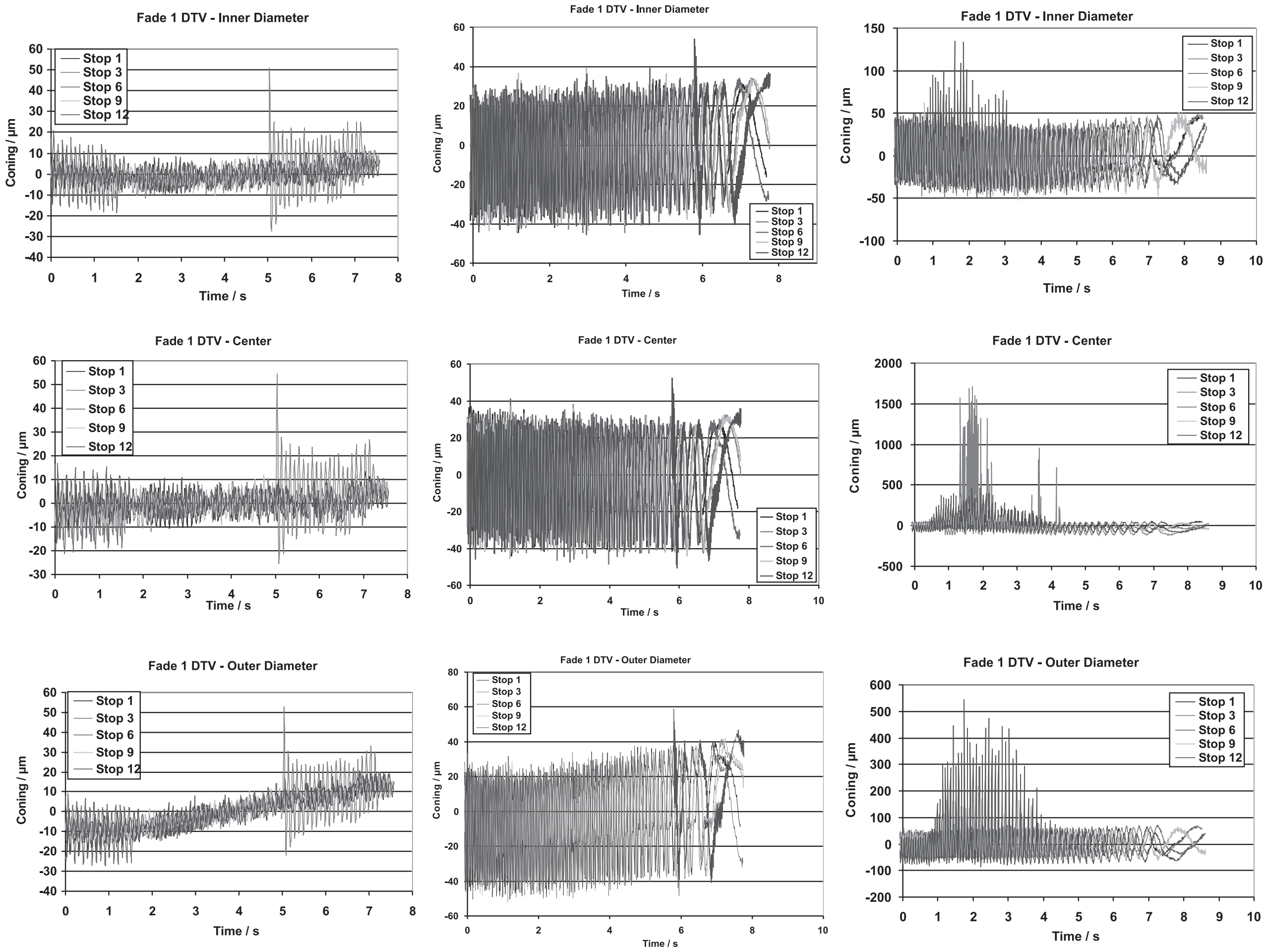


Figure 13. Examination of the DTVs of the original and coated discs through inner, central, and outer diameter in the first fade test by 1000 measurements

of wear on the pads. In addition, in the first fade test procedure, no noticeable fade was observed though the disc and pad temperature reached about 700 °C.

- In all the tests, disc temperature was measured higher than pad temperature, except for the fact that higher temperatures were recorded on the pad in some of the tests due to the thermal barrier effect of the disc coated with Al_2O_3-TiO_2.
- That the DTV value of R2 was higher than that of R1 might have been caused by its high CoF. In addition, the excessive DTV deviation occurring in R3 was caused by the mass transfer from pads to disc as a result of thermal barrier effect. Both R3 and R2 were exposed to higher running temperatures than R1 during braking and this had an effect on DTVs.
- Wear in R2 was seen more than R1 because of high running temperature, high CoF and non-uniform rotating geometry.

Following from these conclusions, the suggestions are made as:

- It is possible that the wear in R2 could be reduced by using coating powders of nano-structure.
- If a proper pad composition is selected, R3 is one of the alternatives to be used in vehicles.

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