

EFFECTS OF SUBSTRATE SURFACE FINISH ON TRIBOLOGICAL PERFORMANCE AND SURFACE TOPOGRAPHY OF THERMALLY SPRAYED WC CERMET COATING

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Abstract: In this study, tribological characteristics and surface topographies of thermally sprayed WC-Cr-Ni cermet coating were investigated experimentally under lubricated rolling with sliding contact conditions. Hi-HVOF sprayed WC cermet coatings were deposited onto the axially ground, blasted and circumferentially ground roller specimens made of an induction hardened carbon steel. It was found that under a contact pressure 1.4 GPa, cermet coating showed a high durability and life of the coating was not influenced by the substrate surface finish. It was also found that coefficient of friction and surface temperature were hardly affected by the substrate surface finish. On the other hand, after running, surface topographical parameters such as skewness, kurtosis and surface roughness were significantly influenced depending on the substrate surface finish. Namely, after the running-in process, the skewness in the case of circumferentially ground substrate became much more negative than that in the case of axially ground or blasted substrate. In addition, kurtosis and surface roughness of the coated surface were much more influenced in the case of circumferentially ground substrate than that in the case of axially ground or blasted substrate.

Keywords: Substrate Surface Finish, Tribological Performance, Surface Topography, WC-Cr-Ni Cermet

1 Introduction

Modern technology is continually demanding low friction and high wear-resistant materials in order to improve the tribological performance of machine elements such as rolling element bearings, gears, cams and tappets. The strongest demand has been for the coating materials particularly tungsten carbide (WC) based cermets for enhancing the surface characteristics of a material or extending its service life. This is because the hard WC

particles lead to high coating hardness while the metal binder supplies the necessary coating toughness, thus forms not only very hard but also tough cermet system, making it suitable for numerous industrial applications to combat wear [1]. These cermet coatings can be prepared by the conventional type high velocity oxy-fuel flame spraying (HVOF) or by the high energy type flame spraying (Hi-HVOF) [2]. However, the investigations on the tribological properties of these thermally sprayed cermet coatings under rolling with sliding contact conditions have been limited [3-5].

The effects of coating thickness and slip ratio on durability of HVOF sprayed WC-Cr-Ni cermet coating were investigated under lubricated rolling/sliding contact conditions [6]. It was found that durability of cermet coating was significantly influenced by the slip ratio and coating thickness. The influence of spray parameters on the particle in-flight properties and coating properties during HVOF spraying of WC cermet powder was investigated [7]. It was found that the spray parameters such as the total gas flow rate, the powder feed rate and the spray distance influenced the particle properties and the coating properties to different degrees. Durability of WC cermet coating was examined under lubricated rolling with sliding contact [8]. It was found that durability was significantly influenced by the substrate surface finish. Surface durability of WC cermet coated steel roller was examined under rolling with sliding contact and it was found that durability or life to flaking of coated roller was greatly influenced by the substrate material [9].

In this study, tribological characteristics and surface topographies of thermally sprayed WC-Cr-Ni cermet coating were investigated

experimentally under lubricated rolling with sliding contact conditions. Coatings were deposited onto the axially ground, blasted and circumferentially ground roller specimens made of induction hardened carbon steel by means of Hi-HVOF spraying. The effects of substrate surface finish on durability of cermet coating, coefficient of friction and surface temperature were investigated. In addition, the effects of substrate surface finish on surface topographical parameters such as skewness, kurtosis and surface roughness were also examined.

2 Experimental Details

2.1 Test Specimen (coated roller) and Mating Non-coated Roller

The substrate material of the test specimen is an induction hardened carbon steel and the coating material is WC-Cr-Ni cermet. The material of the mating non-coated roller is a carburized and hardened chromium molybdenum steel. Chemical compositions of the substrate material and the coating material are shown in Table 1. Chemical composition of the mating non-coated roller is shown in Table 2.

Table 1 Chemical composition (by mass%) of test specimen (coated roller)

Induction hardened carbon steel (substrate)	Fe	C	Si	Mn	P	S	Cu	Ni	Cr
	Balance	0.44	0.19	0.75	0.01	0.03	0.16	0.50	0.14
Thermally sprayed coating	WC			Cr			Ni		
	Balance			20			7		

Table 2 Chemical composition (by mass%) of mating non-coated roller

Carburized hardened steel	Fe	C	Si	Mn	P	S	Cu	Mo	Cr
	Balance	0.18	0.30	0.90	0.01	0.03	0.10	0.35	1.25

2.2 Substrate Surface Preparation and Thermal Spraying Conditions

Before applying the thermally sprayed coating onto the induction hardened carbon steel substrate, the substrate surface was prepared so that coating material can adhere with the substrate material. Three types of substrate surfaces were prepared by axially grinding, shot-blasting and circumferential grinding.

After surface preparation, the maximum surface roughness was $R_{\max}=7.0 \mu\text{m}$. After that, WC-Cr-Ni cermet coating was formed onto the axially ground, blasted and circumferentially ground roller specimens by means of the high energy type flame spraying (Hi-HVOF) and the spraying conditions are shown in Table 3.

Table 3 Spraying conditions

Spraying process		Hi-HVOF
Pressure, MPa	Oxygen	1.0
	Fuel*	0.9
Flow rate, m ³ /h	Oxygen	53.6
	Fuel*	0.02
Sprayed distance, mm		380
Velocity of coating particles, m/s		1080
Velocity of gas, m/s		2160

* Fuel: Kerosene

2.3 Specifications of Rollers

WC-Cr-Ni cermet coating of about $60 \mu\text{m}$ in thickness was prepared. After spraying, the contact surface of coated roller was finished smooth to a mirror-like condition with a maximum surface roughness $R_{\max}=0.2 \mu\text{m}$ by

grinding and subsequent polishing. The micro-Vickers hardness of the coating formed by Hi-HVOF was $HV \approx 1130$ (test load: 2.94 Newton). The maximum surface roughness of non-coated roller was $R_{\max}=5.0 \mu\text{m}$. The detail specifications of coated roller and mating

non-coated roller are shown in Table 4.

Table 4 Specifications of coated and non-coated rollers

Diameter of coated and non-coated rollers, mm	60
Micro-Vickers hardness of coating (Hi-HVOF), HV	1130
Micro-Vickers hardness of substrate (Induction hardened), HV	680
Micro-Vickers hardness of non-coated roller, HV	800
Maximum surface roughness of the substrate, μm	7.0
Maximum surface roughness of coated roller, μm	0.2
Maximum surface roughness of non-coated roller, μm	5.0
Effective track width in line contact condition, mm	10
Coating thickness, μm	60

2.4 Testing Machine, Test Conditions and Lubricating Oil

Using a two-roller testing machine, experiments were carried out to investigate the tribological characteristics and surface topographies of thermally sprayed WC-Cr-Ni cermet coating under lubricated rolling/sliding contact conditions. In the experiments, using a coil spring the normal load was applied in line contact condition. The normal load which gives the Hertzian contact pressure $P_H=1.4$ GPa was applied. Moreover, under rolling with sliding contact condition, using the gear ratio 25/32, a slip ratio $s=-28.0\%$ was applied. An automatic stopping device was attached with the testing machine and this device worked in response to any abnormal vibration induced by the occurrence of flaking/delamination of coating. In the experiments, durability or life to flaking of coating N is defined as the total number of revolutions of the coated roller. When the testing machine continued to run without any flaking of the coating, the running was discontinued at $N=2.0 \times 10^7$ cycles. The friction force between coated roller and non-coated roller was measured by strain gauges. As lubricant, a paraffinic mineral oil without extreme pressure (EP) additives (kinematic viscosity ν : $62.9 \text{ mm}^2/\text{s}$ at 313 K, $8.5 \text{ mm}^2/\text{s}$ at 373 K, pressure-viscosity coefficient α : 13.3 GPa^{-1} at 313 K) was supplied at a flow rate of $15 \text{ cm}^3/\text{s}$ and at a constant oil temperature of 318 K.

3 Results and Discussion

Fig. 1 shows the effect of substrate surface finish on durability or life to flaking of WC cermet coating under a contact pressure $P_H=1.4$ GPa and slip ratio $s=-28.0\%$ when the substrate material was induction hardened carbon steel.

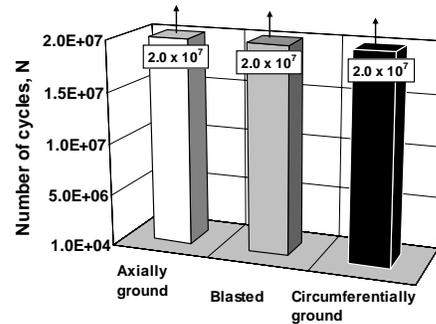


Fig. 1 Effect of substrate surface finish on durability or life to flaking of WC cermet coating ($P_H=1.4$ GPa, $s=-28.0\%$)

From the figure it can be seen that the axially ground substrate roller showed high durability and coating showed a long life over $N=2.0 \times 10^7$ cycles. It can also be observed that cermet coating showed a high durability and it was possible to run over $N=2.0 \times 10^7$ cycles when the substrate surface was blasted or circumferentially ground.

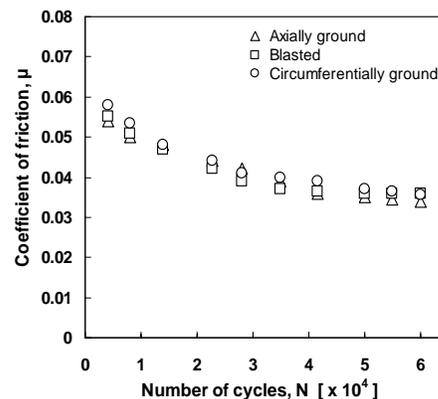


Fig. 2 Effect of substrate surface finish on change in the coefficient of friction ($P_H=1.4$ GPa, $s=-28.0\%$)

Fig. 2 illustrates the effect of substrate surface finish on change in the coefficient of friction with the number of cycles. From the figure it can be seen that in the case of axially

ground substrate and at the start of running, coefficient of friction was about 0.055 and it decreased gradually with the number of cycles and came to a steady value within a short time. From the figure it can also be noticed that the change in the coefficient of friction with the number of cycles followed almost the same trend when the substrate surface was blasted or circumferentially ground. From the obtained results it was confirmed that coefficient of friction was hardly influenced by the substrate surface finish. However, it could be considered that there was a very little difference in the coefficient of friction during running-in depending on the running conditions.

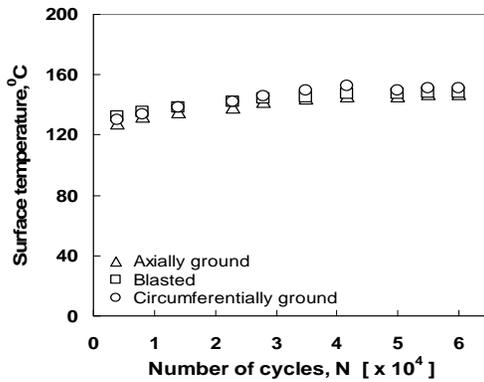


Fig. 3 Effect of substrate surface finish on surface temperature ($P_H=1.4$ GPa, $s=-28.0\%$)

Fig. 3 represents the effect of substrate surface finish on surface temperature of coated roller. From the figure it is apparent that in the case of axially ground substrate, at the start of running, the surface temperature was about 125°C and it increased very steadily with the number of cycles and came to a constant value within a short time. It can also be seen that change in surface temperature followed almost the same trend when the substrate surface was blasted or circumferentially ground. The obtained results revealed that surface temperature was not influenced by the substrate surface finish.

Fig. 4 shows the effect of substrate surface finish on skewness of the coated surface. From the figure it can be observed that before the test, the skewness of coated surface was about -0.6. From the figure it is also seen that in the case of axially ground or blasted substrate, after the test the skewness became about -3.0. On the other hand, in the case of circumferentially ground substrate, after the

test the skewness became about -4.0. The obtained results revealed that after the running-in process, the skewness of the coated surface became much more negative in the circumferentially ground substrate than that in the axially ground or blasted substrate. This means that after the test, the coating on the circumferentially ground substrate became more valley-biased than that on the axially ground or blasted substrate.

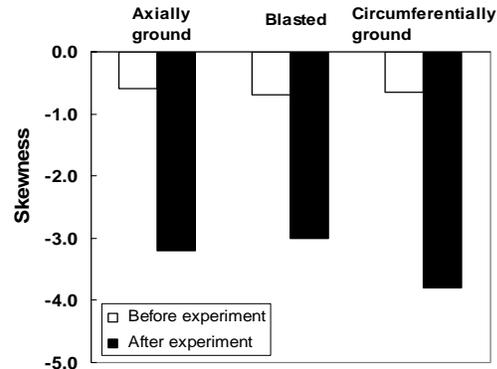


Fig. 4 Effect of substrate surface finish on skewness ($P_H=1.4$ GPa, $s=-28.0\%$)

Fig. 5 exhibits the effect of substrate surface finish on kurtosis of the coated surface. From the figure it can be observed that before the test, the kurtosis of coated surface was about 3.0 but after the test it was increased significantly. Namely, in the case of axially ground or blasted substrate, after the test, the kurtosis of the coated surface became about 14.0.

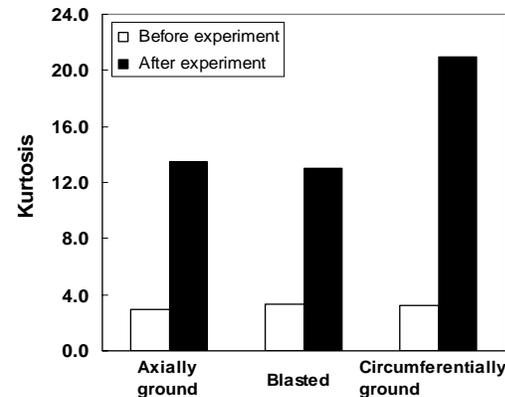


Fig. 5 Effect of substrate surface finish on kurtosis ($P_H=1.4$ GPa, $s=-28.0\%$)

On the other hand, in the case of circumferentially ground substrate, after the test, the kurtosis of the coated surface was remarkably increased and it became about 21.0. From these results it is apparent that after the running-in process, the kurtosis of the coated

surface was much more influenced in the case of circumferentially ground substrate than that in the case of axially ground or blasted substrate. This means that after the test, the coating on the circumferentially ground substrate became much more pointed than that on the axially ground or blasted substrate.

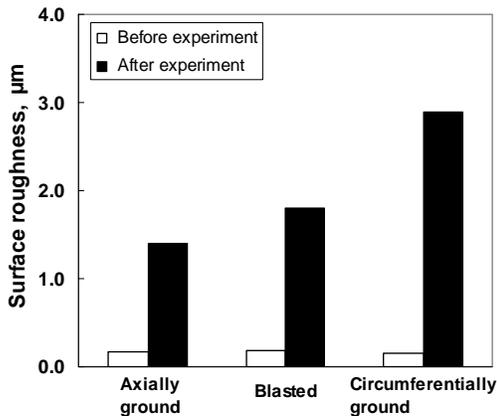


Fig. 6 Effect of substrate surface finish on surface roughness ($P_H=1.4$ GPa, $s=-28.0\%$)

Fig. 6 shows the effect of substrate surface finish on surface roughness of WC cermet coated roller. The coated steel roller was mated with the non-coated carburized hardened steel roller. From the Fig. 6 it is seen that in the axially ground substrate, before experiment, the surface roughness of coated roller was about $0.2 \mu\text{m}$ and after experiment, the surface roughness was greatly increased to about $1.5 \mu\text{m}$. In the case of blasted substrate, after experiment, the surface roughness of the coated roller was also significantly increased and it became about $1.8 \mu\text{m}$. From the figure it is apparent that in the case of circumferentially ground substrate, before experiment, the surface roughness of coated roller was about $0.2 \mu\text{m}$ whereas after experiment, the surface roughness of coated roller was remarkably increased and it became about $3.0 \mu\text{m}$. The obtained results revealed that after running, roughness of the coated surface was much more influenced circumferentially ground substrate than that in the axially ground or blasted substrate.

4 Conclusions

In this study, tribological characteristics and surface topographies of Hi-HVOF sprayed WC-Cr-Ni cermet coating were investigated

under lubricated rolling with sliding contact conditions. The substrate material was an induction hardened carbon steel. The effects of substrate surface finish on durability of cermet coating, coefficient of friction and surface temperature were investigated. The effects of substrate surface finish on surface topographical parameters such as skewness, kurtosis and surface roughness were also examined. From the obtained results it can be concluded that WC-Cr-Ni cermet coating has long life and it was not influenced by the substrate surface finish. The coefficient of friction and surface temperature were hardly influenced by the substrate surface finish. After the running-in process, the skewness of the coated surface was considerably changed and became much more negative in the case of circumferentially ground substrate than that in the axially ground or blasted substrate, and kurtosis and surface roughness of the coated surface were significantly increased. The kurtosis and surface roughness of the coated surface were much more influenced circumferentially ground substrate than that in the axially ground or blasted substrate.

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