INFLUENCE OF SPRAYING PROCESS AND COATING THICKNESS ON DURABILITY OF WC CERMET COATING

Akira Nakajima†, D. M. Nuruzzaman* and Toshifumi Mawatari†
†Department of Mechanical Engineering,
Faculty of Science and Engineering, Saga University
1, Honjo-machi, Saga-shi, Saga 840-8502, Japan
*Department of Mechanical Engineering
Dhaka University of Engineering and Technology,
Gazipur-1700, Bangladesh
Email: dewan052005@yahoo.com

INTRODUCTION

The thermal spraying process is one of the most versatile methods available for deposition of coating materials and it has been applied steadily in various fields of industry as one of the most important material processing or surface modification technologies. During the last 10-15 years, in the field of thermal spraying, main attention has been paid to various high velocity spray processes. The latest coating deposition systems are designed to optimize the velocity and the temperature of the spray particles; hence decreasing the level of in-flight chemical reactions and improving the bonding throughout the coating. To date, there are very limited studies concerning the thermally sprayed coatings. The tribological properties and the durability of these coatings in rolling/ sliding contact conditions are described in detail in Nuruzzaman et al[1].

Experiments were carried out to investigate the relative rolling contact fatigue (RCF) performance of as-sprayed and post-treated functional graded WC-NiCrBSi coatings deposited on bearing steel substrates by JP5000 HVOF system[2]. It was found that coatings heat-treated at an elevated temperature of 1200^{0}C exhibit superior RCF performance over the as-sprayed coatings in full film elastohydrodynamic lubrication. The effects of substrate surface finish and substrate material on durability of WC-Cr-Ni cermet coating were examined under lubricated rolling/sliding contact[3-4]. It was found that life to flaking is greatly influenced by the substrate hardness. It was also found that for low hardness substrate, surface durability of cermet coated steel roller is remarkably affected by the substrate surface finish when the mating surface is rough. Under partial elastohydrodynamic lubrication (EHL) condition, experiments were carried out to investigate the durability of thermally sprayed WC cermet coating[5]. It was found that in case of thermally refined steel substrate, durability of cermet coating is significantly influenced by contact pressure and substrate surface finish. The durability of cermet coated steel roller is much higher than that of non-coated steel roller and substrate surface finish has no effect on the coefficient of friction.

In this work, WC-Cr-Ni cermet coating was formed onto the roller specimens made of a thermally refined carbon steel or an induction hardened carbon steel by means of a high energy type flame spraying (Hi-HVOF) as well as a conventional high velocity oxy-fuel flame spraying (HVOF). The coated steel roller finished to a mirror-like condition was mated with a carburized hardened steel roller without coating. The effects of spraying process, coating thickness and substrate material on the durability of coated surface were examined. Tribological properties such as coefficient of friction and surface roughness were also examined.

EXPERIMENTAL DETAILS

The material of the test specimen (coated roller) and mating non-coated roller are described in detail in Nuruzzaman et al[1]. Prior to thermal spraying, the outer surface of the substrate material was roughened (maximum surface roughness 7.0 μm) by blasting. Then WC-Cr-Ni cermet coating was formed onto the substrate surface not only by the conventional high velocity oxy-fuel flame spraying (HVOF) but also by the high energy type flame spraying (Hi-HVOF). The spraying conditions are shown in Table 1.

The coatings of about 50, 100, 200 and 400 μm in thickness were prepared. After spraying, the contact surface of coated roller was mirror-finished with a maximum surface roughness R_{max}=0.2 μm by grinding and subsequent polishing. The micro-Vickers hardness of the coating formed by HVOF was HV≈960 (test load: 2.94 N) while the hardness of the coating formed by Hi-HVOF was HV≈1130. The hardness of the thermally refined steel substrate was HV≈280 while the hardness of the induction hardened steel substrate was HV≈590. The hardness of the non-coated roller was HV≈770. The surface roughness of the mating non-coated roller was R_{max}=0.2 μm. The details of the testing machine and lubricant properties are described in Nuruzzaman et al[1]. Tests were conducted in rolling/sliding contact condition and using a gear ratio of 27/31 or 25/32, a slip ratio of s=-14.8% or s=-28.0% was applied. The effective track width was 10 mm in line contact condition. The normal load which gives the Hertzian contact pressure P_H=1.2 GPa or P_H=1.4 GPa was applied.

Table 1: Spraying conditions

Spraying process		HVOF	Hi-HVOF
Pressure, MPa	Oxygen	0.7	1.0
	Fuel*	0.5	0.9
Flow rate, m^3/h	Oxygen	28.8	53.6
	Fuel*	4.2	0.02
Sprayed distance, mm		150	380
Velocity of coating particles, m/s		700	1080
Velocity of gas, m/s		1620	2160

* Fuel: Propylene (HVOF), Kerosene (Hi-HVOF)

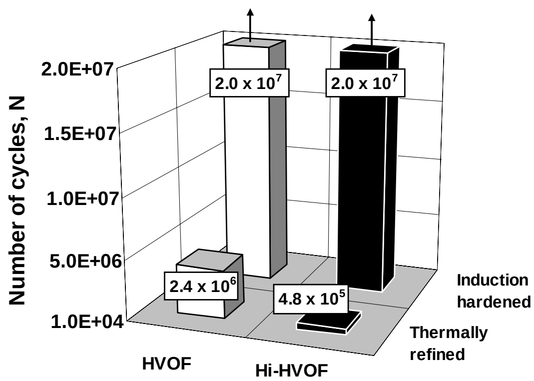

Figure 1: Effect of spraying process and substrate material on durability of WC cermet coating (Slip ratio s=-14.8%, thickness=50 µm)

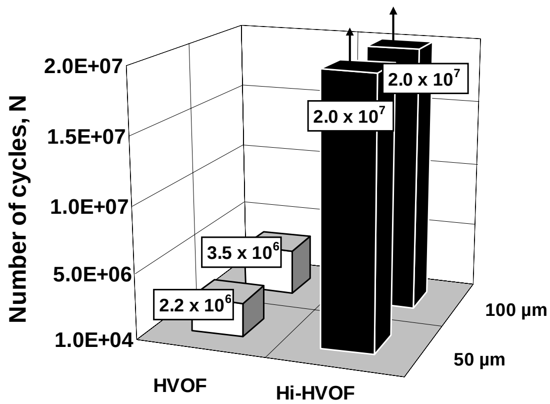

Figure 2: Effect of spraying process and coating thickness on durability of WC cermet coating (Induction hardened, P_H=1.4 GPa)

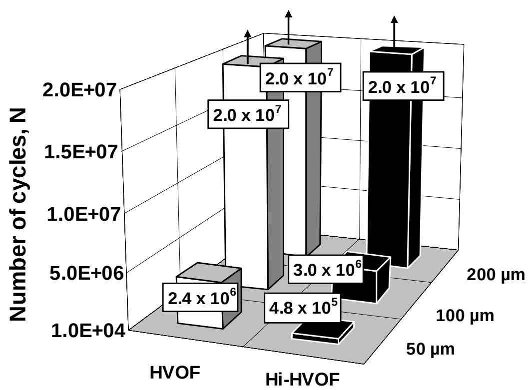

Figure 3: Effect of spraying process and coating thickness on durability of WC cermet coating (Thermally refined, P_H=1.2 GPa)

RESULTS AND DISCUSSION

Figure 1 shows the effect of spraying process and substrate material on durability or life to flaking of WC cermet coating under a slip ratio s=-14.8% and when the coating thickness was about 50 µm. From the figure it can be seen that in the case of thermally refined steel substrate, WC cermet coating formed by HVOF exhibited a short life and it was possible to run up to $N=2.4\times10^6$ cycles under a contact pressure P_H=1.2 GPa. On the other hand, coating formed by Hi-HVOF showed much shorter life than that formed by HVOF and flaking/delamination of the coating occurred at the early stage of running $N=4.8\times10^5$ cycles. In the case of induction hardened steel substrate, coating formed by HVOF showed a fairly long life over $N=2.0\times10^7$ cycles under P_H=1.2 GPa and the Hi-HVOF sprayed coating also showed a long life even when the contact pressure was P_H=1.4 GPa and the effect of spraying process on durability of cermet coating was hardly recognized.

Figure 2 illustrates the effect of spraying process and coating thickness on durability of WC cermet coating in the case of induction hardened steel substrate and under a contact pressure of P_H=1.4 GPa. As shown in the figure, HVOF coating showed a short life $N=2.2\times10^6$ cycles whereas Hi-HVOF coating showed a long life over $N=2.0\times10^7$ cycles when the coating thickness was 50 µm and under a slip ratio s=-14.8%. From the figure it can also be seen that due to the increase in the coating thickness from 50 µm to 100 µm, durability of HVOF coating was not much improved. In this case, durability of coating again exhibited a short life $N=3.5\times10^6$ cycles which is slightly higher than the durability $N=2.2\times10^6$ cycles. On the other hand, Hi-HVOF coating showed a long life as before and it was possible to run over $N=2.0\times10^7$ cycles even when the slip ratio was s=-28.0%.

Figure 3 shows the effect of spraying process and coating thickness on durability of WC cermet coating in the case of thermally refined steel substrate and under a contact pressure P_H=1.2 GPa and a slip ratio s=-14.8%. Results are shown (from Fig. 1) when the coating thickness was 50 µm. From the figure it is very clear that durability or life to flaking of HVOF coating was remarkably improved from $N=2.4\times10^6$ cycles to $N=2.0\times10^7$ cycles due to the increase in the coating thickness from 50 µm to 100 µm. It can also be seen that, durability of Hi-HVOF coating greatly increased due to the increase in the coating thickness and it showed an improved life from $N=4.8\times10^5$ cycles to $N=3.0\times10^6$ cycles. Moreover, it can be observed that coating formed by HVOF showed much longer life than that formed by Hi-HVOF when the coating thickness was up to 100 µm. From the figure it is also apparent that as the coating thickness was increased to 200 µm, WC cermet coating exhibited a long life over $N=2.0\times10^7$ cycles and durability or life to flaking was hardly influenced by the spraying process.

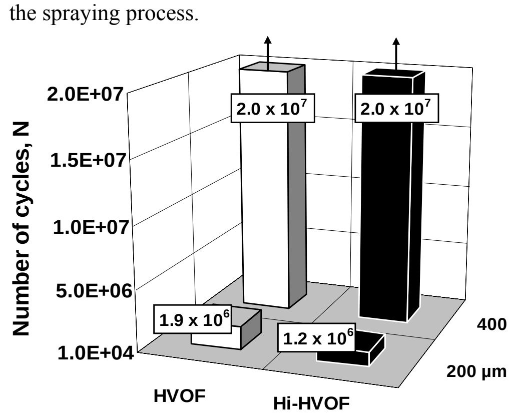

Figure 4: Effect of spraying process and coating thickness on durability of WC cermet coating (Thermally refined, P_H=1.4 GPa)

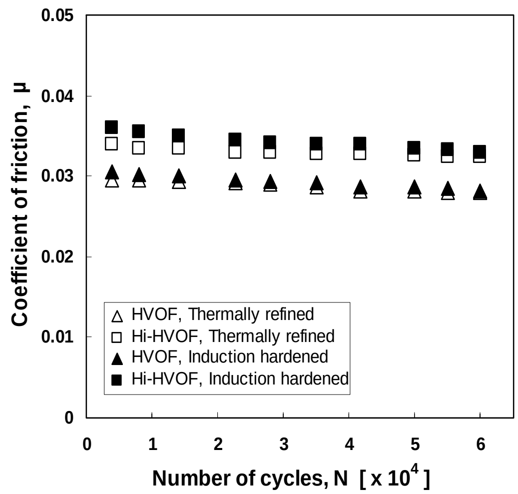

Figure 5: Effect of spraying process and substrate material on change in the coefficient of friction (s=-14.8%)

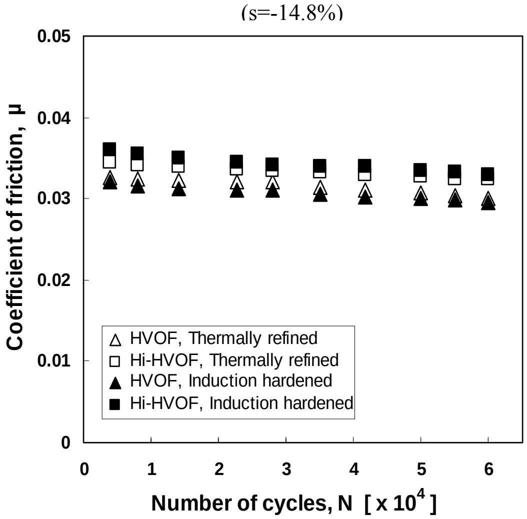

Figure 6: Effect of spraying process and substrate material on change in the coefficient of friction (P_H=1.4 GPa)

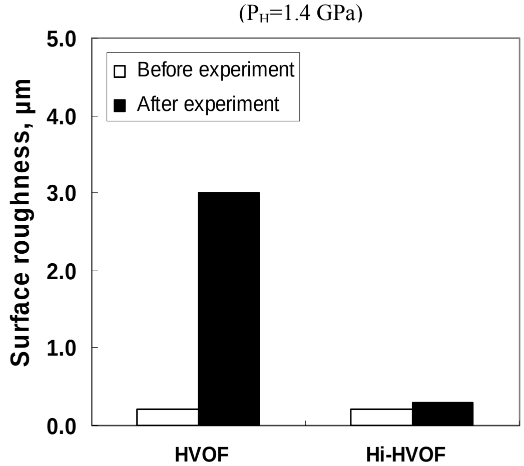

Figure 7: Effect of spraying process on surface roughness of WC cermet coated roller (Thermally refined, P_H=1.4 GPa)

Figure 4 shows the effect of spraying process and coating thickness on durability of WC cermet coating in the case of thermally refined steel substrate and under a higher contact pressure of P_H=1.4 GPa and a slip ratio s=-14.8%. From the figure it can be noticed that coatings formed by both HVOF and Hi-HVOF showed a short life even though the coating thickness was 200 μm. Moreover, coating formed by HVOF showed higher durability than that formed by Hi-HVOF. With the increased coating thickness 400 μm, durability of coating was significantly increased. In this case, the coating exhibited a long life over N=2.0×10^7 cycles and durability or life to flaking of the cermet coating was not affected by the spraying process.

Figure 5 exhibits the effect of spraying process and substrate material on change in the coefficient of friction under a slip ratio s=-14.8%. In the case of thermally refined steel substrate and under a contact pressure P_H=1.2 GPa, at the start of running, the coefficient of friction was about 0.029 for HVOF coating and it decreased very slowly with the number of cycles and came to a steady value within a short time. On the other hand, for Hi-HVOF coating, the coefficient of friction was little higher and at the start of running it was about 0.034 and followed almost the same trend as before. In the case of induction hardened steel substrate and under P_H=1.2 GPa, results are shown for HVOF coating. Under P_H=1.4 GPa, results are also shown for Hi-HVOF coating. From the figure it is apparent that coefficient of friction was hardly influenced by the substrate material. However, it could be considered that there is a very little difference in the coefficient of friction during running-in depending on the running conditions.

Figure 6 also shows the results of friction measurement as the coefficient of friction under a slip ratio s=-14.8%. In the case of thermally refined steel substrate and under a higher contact pressure P_H=1.4 GPa, at the start of running, the coefficient of friction was about 0.033 for HVOF coating, which is little higher than that under P_H=1.2 GPa (Fig. 5). Moreover, for Hi-HVOF coating, at the start of running the coefficient of friction was about 0.037 which is also little higher than that under P_H=1.2 GPa (Fig. 5). From the figure it can also be noticed that the change in the coefficient of friction followed almost the same trend as in Fig. 5. Results are also shown for the induction hardened steel substrate and from the obtained results it was confirmed that coefficient of friction is hardly affected by the substrate material and there is a little difference in the coefficient of friction depending on the running conditions.

Figure 7 shows the effect of spraying process on surface roughness of WC cermet coated roller in the case of thermally refined steel substrate and under a contact pressure of P_H=1.4 GPa. As shown in the figure, for HVOF coating, before experiment the surface roughness of coated roller was 0.2 μm and after experiment it was remarkably increased to 3.0 μm. On the other hand, for Hi-HVOF coating, after running the surface roughness of coated roller was slightly increased and it became 0.3 μm.

Figure 8 shows the effect of spraying process on surface roughness of WC cermet coated roller in the case of induction hardened steel substrate and under a contact pressure of P_H=1.4 GPa. As shown in the figure, surface roughness of the coated roller was markedly influenced depending on the spraying process. Namely, for HVOF coating, after experiment the surface roughness of coated roller was significantly increased to about 3.0 μm whereas,

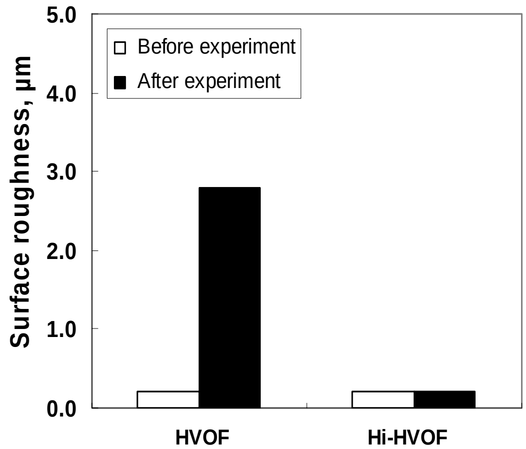

Figure 8: Effect of spraying process on surface roughness of WC cermet coated roller (Induction hardened, P_H=1.4 GPa)

for Hi-HVOF coating, after experiment the surface roughness of coated roller was not changed.

CONCLUSION

The effects of spraying process, coating thickness and substrate material on the durability or life to flaking of WC-Cr-Ni cermet coating were investigated. The properties such as coefficient of friction and surface roughness were also examined. The results are summarized as follows:

- Under 1.2 GPa and in the case of thermally refined steel substrate, coating formed by HVOF exhibited higher durability than that formed by Hi-HVOF when the coating thickness was 50 µm. With 100 µm thickness, HVOF coating showed a longer life whereas Hi-HVOF coating showed a shorter life. With 200 µm thickness, coating showed a longer life regardless of the spraying process. In the case of induction hardened steel substrate, HVOF coating showed a longer life when the coating thickness was 50 µm.
- Under 1.4 GPa and in the case of induction hardened steel substrate, coating formed by HVOF generally exhibited a short life when the coating thickness was 50 or 100 µm whereas coating formed by Hi-HVOF showed a longer life. In the case of thermally refined steel substrate and with the thickness 200 µm, both HVOF and Hi-HVOF coatings showed a shorter life. However, with the increased thickness of 400 µm, both HVOF and Hi-HVOF coatings showed high durability and the difference in the life between both coatings was hardly recognized.
- Coating formed by Hi-HVOF showed higher coefficient of friction than that formed by HVOF. Moreover, coefficient of friction was hardly influenced by the substrate material.
- After experiment, surface roughness of coating was remarkably increased in case of coating formed by HVOF whereas it was not much changed in case of coating formed by Hi-HVOF. In addition, surface roughness was not much influenced by the substrate material.

REFERENCES

1. D. M. Nuruzzaman, A. Nakajima. and T. Mawatari, “Characteristics of Thermally Sprayed WC Cermet Coating under Lubricated Rolling with Sliding Contact,” *J. Mechanical Engineering*, Vol. 37, pp.18-23, 2007.

2. S. Stewart, R. Ahmed and T. Itsukaichi, “Rolling Contact Fatigue of Post-Treated WC-NiCrBSi Thermal Spray Coatings”, *Surface & Coatings Technology*, Vol. 190, pp. 171-189, 2005.

3. A. Nakajima, D. M. Nuruzzaman, T. Mawatari and M. Yoshida, “Effect of Substrate Surface Finish on Durability of Thermally Sprayed WC Cermet Coating under Rolling/Sliding Contact,” *Japanese Journal of Tribology*, Vol. 50(4), pp. 437-448, 2005.

4. D. M. Nuruzzaman, A. Nakajima. and T. Mawatari, “Effects of Substrate Surface Finish and Substrate Material on Durability of Thermally Sprayed WC Cermet Coating in Rolling with Sliding Contact,” *Tribology International*, Vol. 39(7), pp.678-685, 2006.

5. D. M. Nuruzzaman, A. Nakajima. and T. Mawatari, “Study on the Durability of Thermally Sprayed WC Cermet Coating in Partial EHL Contacts,” *Proc. of the 6th Int. Conf. on Mechanical Engineering (ICME’2005)*, pp. 1-6, 2005.