# Low friction coatings prepared by high performance type spray gun

O. Fukumasa[a], K. Osaki[a], S. Fujimoto[a], C.P. Lungu[b], Ana Mihaela Lungu[b]

[a]*Department of Electrical and Electronic Engineering,*
*Faculty of Engineering, Yamaguchi University,*
*Tokiwadai 2-16-1, Ube 755-8611, Japan*
[b]*National Institute for Lasers, Plasma and Radiation Physics,*
*Atomistilor No. 1, Bucharest, Romania*

**Abstract**

To produce low friction coatings to be used as overlays for automobile journal bearings and to perform depositions with high rate, we prepared composite coatings of Ag and graphite by using the new-type spray gun based on the forced constricted type plasma jet generator (i.e. the high performance type spray gun). Characterization of the films showed the graphite phase dispersed into the Ag matrix, analyzed by optical microscopy, electron probe microanalysis and X-ray diffraction. The coefficient of friction of the Ag/graphite overlay measured using ball-on-disc tribometer was reduced by a factor of five compared with that of bronze substrate and by factor of two compared with that of the Ag/graphite overlay prepared by ECR sputtering.

**Key words:** plasma spraying, silver, Graphite, X-ray diffraction, ball-on-disc test, coefficient of friction

## 1. Introduction

Low friction coating materials are new classes of advanced materials, which exhibit a reduced coefficient of friction in dry sliding and raised wear resistance. Due to the demand of high power and high-speed automotive engines, the engine moving parts have to be improved in tribological characteristics. The plain bearings consist of steel backing, bearing alloy and an electroplated sliding layer or overlay. The bearing alloy is copper or aluminum base as a rule, the sliding layer consists of a ternary dead-tin-copper alloy which principally performs the following function: (i) adapts to the surface of the shaft during the running phase; (ii) absorbs foreign particles potentially present in the oil; (iii) provides corrosion protection for the underlying lead-bronze alloy and (iv) provides emergency running behavior under conditions of oil shortage [1, 2]. The overlays that provide seizure and wear resistance and conformability are usually made by electroplating of 10-30 $\mu$m thick lead alloy. The lead matrix is soft and has relatively low fatigue resistance under high-pressure conditions. New ecologically tailored materials and new deposition procedures are needed to improve tribological and mechanical characteristics of the overlay.

We previously reported the formation of Ag/graphite overlays by plasma sputtering [3] and spray coating of alumina mono-layer [4] by using thermal plasma reactor based on the forced constricted type plasma jet generator [5]. Ag matrix overlays having low coefficient of friction in dry sliding were found to increase significantly the seizure resistance of the plain bearings tested in conditions close to real operation [6]. In this paper, we study further tribological coatings of Ag and Ag/graphite by using the new-type spray gun (i.e. the high performance type spray gun) [7, 8], in order to obtain overlays with lower coefficient of friction and higher deposition rates.

## 2. Experimental procedures

The high performance type device consists of the rod anode, the insulated constrictor disk and the rod cathode, as can be seen schematically in Fig. 1. They have the nozzle structure with the same diameter. The arc in this system is maintained at a constant length, and strongly constricted by the insulated disk, the local constricting ring and the working gas (Ar). As a result, a stable and high power plasma jet is produced under various operating conditions. More details were presented elsewhere [7, 8].

In this system, powder particles are injected concentrically into the arc column. So, the whole arc column and the plasma jet region work as the interaction region with the injected powder particles. Injected powder particles are efficiently heated and melted and are ejected from the nozzle symmetrically. The plasma spray gun is fed with Ag powder and a mixture of Ag and graphite of 20μm in mean diameter. The mixture (Ag 80 wt.% and graphite 20 wt.%) was prepared by milling using $SiO_2$ balls during 24 h.

Typical processing conditions were: Ar flow rate; 50 l/min. plasma arc power; 3 kW, powder feeding rate; 0.1-0.2 g/min, deposition time; 1 min and pressure; ambient. Prior to the depositions the substrates were exposed to the overlays. Temperatures of the substrates measured by a thermocouple were found to be 250, 180 and 100 ℃ during depositions accomplished at 3, 4 and 7 cm, distance, respectively.

Characterization of prepared films was made as follows: (i) the inclusion of the graphite into the silver matrix was detected by optical microscopy (OM); electro probe microanalysis (EPMA) and X-ray diffraction (XRD), (ii) Vickers hardness of the coatings was measured by using and Akashi instrument, using 25gf load and 15 s indentation time and (iii) the coefficient of friction of the deposited film was measured by using a ball-on-disk tribometer (CSEM Instrument-Switzerland) at room temperature and 50% relative humidity of air using bearing steel ball of 6 mm in diameter as a counter material. The applied loads were 1 and 5 N and sliding radii 3 and 4 mm were chosen. The sliding speed was kept constantly at 0.1 m/s in all the measurement.

**3. Experimental results and discussion**

For preparation of spray coatings, the substrate was sweeping perpendicularly on the plasma jet axis in a horizontal plane or fixed at a certain substrate position relative to the nozzle exit. When the substrate was fixed, thickness distribution of the Ag and Ag/graphite overlays was uniform around the center axis of the jet suggesting symmetrical ejection of the melted particles. Maximum height of the depositions shaped as form of hills prepared at 3, 4 and 7 cm distances from the nozzle exit were 640, 240 and 100 μm, respectively. When a sweeping device moved substrates perpendicularly to the jet axis the prepared overlays were uniform along the sweeping direction and thickness was 100, 35 and 25 μm correspondingly to the deposition distances of 3, 4 and 7 cm. Deposition rates were between 100 and 25 μm/min, larger than in the case of the ECR sputtering (≈ 0.1 μm/min) [3, 6].

Fig. 2 shows and OM cross-sectional view of the Ag and Ag/graphite overlays. The Ag overlay was dense with small number of pores included. The graphite represented by black zones id clearly seen in the Ag/graphite overlay. EPMA cross-sectional analysis of the Ag/graphite overlay reveals the dispersion of the graphite into the Ag matrix as can be seen in Fig. 3. Graphite concentrations into the overlays were: 16 ± 2, 12 ± 2 and 8 ± 3 wt.% for 3, 4 and 7 cm deposition distances, respectively.

The graphite phase (Graphite-2H, hexagonal) was identified from the XRD pattern of the Ag/graphite overlay as can be seen from the zoom part of Fig. 4. Mainly, peaks were assigned to silver.

Vickers hardness of the coatings was found to be 25 ± 3, 36 ± 4 and 45 ± 5 for 3, 4 and 7 cm deposition distances, respectively. The Vickers hardness of the bronze substrate was 300 ± 15, of the pure Ag coating was 100 ± 10, being in the same range as the Ag coating prepared by sputtering. The fact that the hardness was reduced with decreasing the deposition distance was determined by the concentration of the graphite into the silver matrix. At lower distance between the nozzle exit and the substrate, the graphite concentration was found to be higher. At increased distances, some graphite particles were oxidized CO of $CO_2$ gases.

Fig. 5 shows frictional characteristics of bronze, Ag/graphite and pure Ag coatings tested at loads of 1 and 5 N, respectively. The reduction of the coefficient of friction can be observed in both cases. For the Ag/graphite coatings tested at high load, (i.e. 5 N case) the reduction of the coefficient of friction appears more remarkably. This suggests the predominant influence of the graphite solid lubricant inclusion in the silver matrix [9]. As shake of comparison, the coefficients of friction of the Ag overlay and Ag/graphite overlays prepared by ECR sputtering were in the range of 0.6 ± 0.1 and 0.45 ± 0.05, respectively [3, 6]. The coefficient of the Ag overlay was in the same range for both cases, deposition rate being higher in the plasma spray case. Contrarily, the coefficient of friction of the Ag/graphite overlay prepared by plasma spray was two times lower than the Ag/graphite overlay prepared by sputtering. We note that this behavior is caused by the graphite phase that was prepared by using only plasma spray deposition method.

The low coefficients of friction of the Ag/graphite overlays prepared by the method presented in this paper allow them to be used as sliding layers in order to increase the seizure resistance of the plain bearings as was demonstrated previously by sputtering [10]. The hardness of Ag/graphite overlay was about one quarter lower than that of the Ag overlay and about one-tenth lower than that of the bronze substrate, as mentioned above, leading to increase the embedability and the conformability of the overlays.

## 4. Conclusions

In order to demonstrate the application feasibility of the plasma electrode type spray gun reactor based on the forced constricted type plasma jet generator for fabricating tribological materials, we have prepared the Ag and Ag/graphite overlays for engine bearings. The powder particles injected into the arc were efficiently heated and melted and were ejected from the nozzle symmetrically determining high deposition rates. The coefficients of friction of the Ag and Ag/graphite overlays was found to be reduced by a factor of two and five, respectively, compared with that of the bronze used as substrate measured using a CSEM pin-on-disc tribometer in dry sliding. The coefficient of friction of the Ag/graphite overlay was found to be two times lower than of the Ag/graphite overlay prepared by sputtering. The graphite phase was found to be preserved into the silver matrix.

## Acknowledgements

One of the authors (C.P. Lungu) would like to express his gratitude to New Energy and Industrial Development Organization (NEDO) Japan for the financial support. A part of work id financially supported by a Grant-in-aid for University and Society Collaboration from Japanese Ministry of Education, Culture, Sports, Science and Technology.

## References


[1] H. Ishikawa, K. Nomura, Y. Mizuno, H. Michioka, Y. Fuwa, S. Yasuhara, SAE Technical Paper Series No. 960988, (1996) 1.

[2] K.H. Grunthaler, H.U. Huhn, K. Muller, K. Statschko, J.R. Toth, SAE Technical Paper Series No. 960984, (1996) 1.

[3] C.P. Lungu, K. Iwasaki, J. IAPS 8 (2000) 65.

[4] O. Fukumasa, Oyo Butsuri 67 (1998) 181, in Japanese.

[5] O. Fukumasa, Thin Solid Films 390 (2001) 39.

[6] C.P. Lungu, K. Iwasaki, Vacuum 66 (2002) 385.

[7] K. Osaki, H. Ashida, O. Fukumasa, N. Tada, A. Kobayashi, Proceeding First International Symposium of Applied Plasma Science, (1997) 61.

[8] K. Osaki, O. Fukumasa, S. Fujimoto, A, Kobayashi, Vacuum 65 (2002) 305.

[9] A. Savan, E. Pfluger, R. Goller, W. Gissler, Surf. Coat. Technol. 126 (2000) 159.

[10] C.P. Lungu, K. Iwasaki, T. Kawachi, H. Ishikawa, Formation of seizure resistant surface microstructures by electron cyclotron resonance plasma sputtering, in: F. Franek, W.J. Bartz, A. Pauschitz (Eds.), Tribology 2001, The Austriam Tribology Society, 2001, pp. 291-298.

**Figure Captions**

**Fig. 1**. Schematic draws of the high performance type spray gun.

**Fig. 2**. OM cross-sectional view of the Ag and Ag/graphite overlays.

**Fig. 3**. EPMA characteristic X-ray images of C inclusions into the Ag matrix presented as a gray scale.

**Fig. 4**. XRD pattern of Ag/graphite coating deposited at 3-cm distance from the nozzle exit. The zoom part of the figure shows the characteristic peak ($2\theta = 26.4^{\circ}$) of graphite (Graphite-2H, hexagonal).

**Fig. 5**. Frictional characteristics of the Ag and Ag/graphite coatings prepared at 3-cm distance from the nozzle and of the bronze substrate. In this case substrates were fixed.

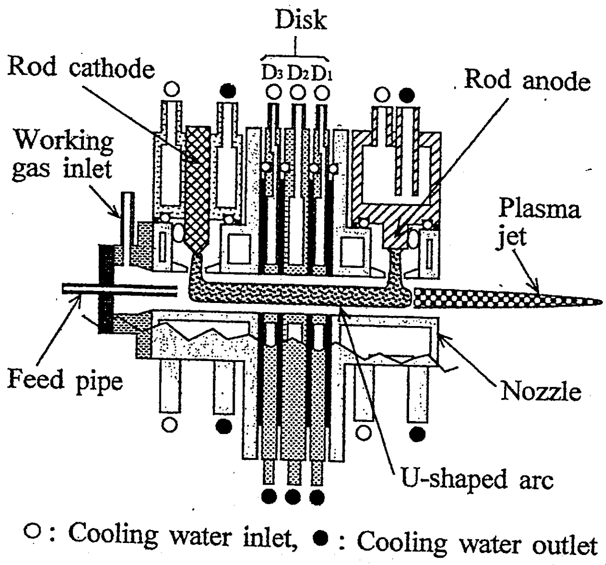


**Fig. 1**. Schematic draws of the high performance type spray gun..

**O. Fukumasa, K. Osaki and S. Fujimoto/ C.P.Lungu and Ana Mihaela Lungu**

**LOW FRICTION COATINGS PREPARED BY PLASMA ELECTRODE TYPE SPRAY GUN**

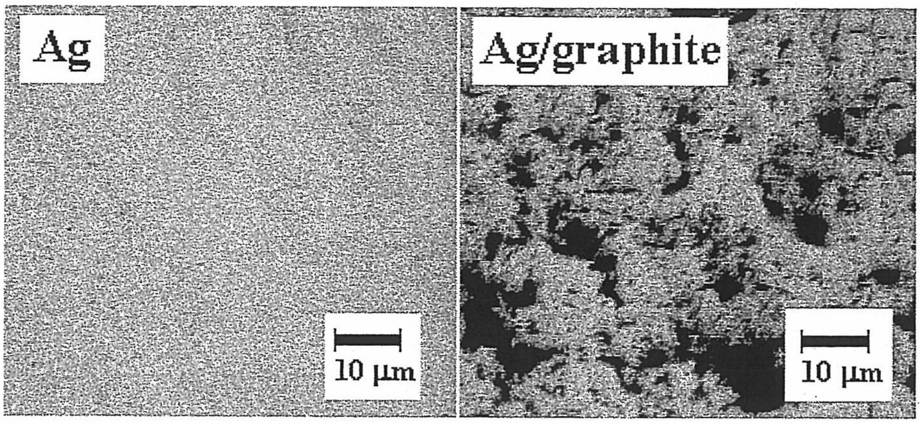


**Fig. 2** OM cross-sectional view of the Ag and Ag/graphite overlays.

**O. Fukumasa, K. Osaki, S. Fujimoto, C. P. Lungu and Ana Mihaela Lungu**

LOW FRICTION COATINGS PREPARED BY PLASMA ELECTRODE TYPE SPRAY GUN

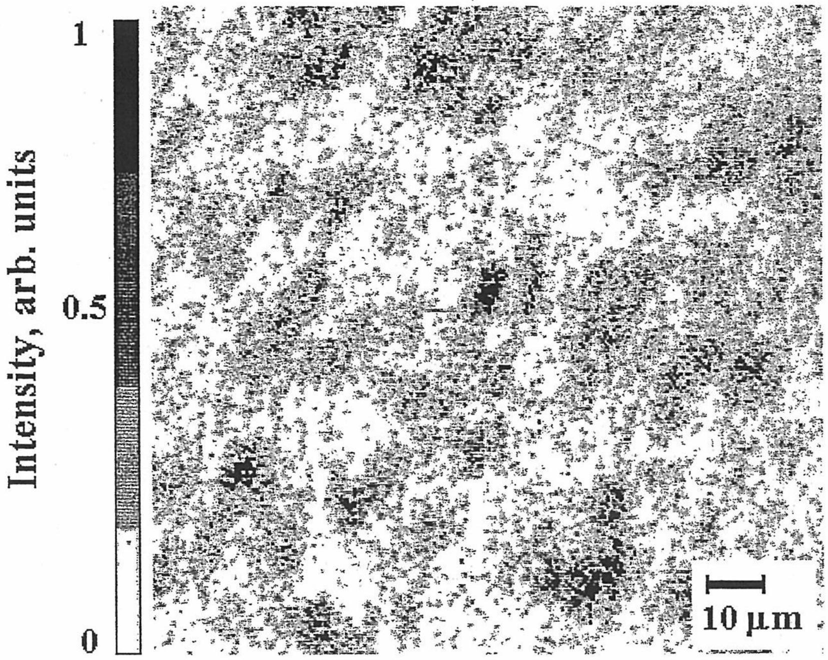


**Fig. 3** EPMA characteristic X-ray images of C inclusions into the Ag matrix presented as a gray scale.

O. Fukumasa, K. Osaki, S. Fujimoto, C. P. Lungu and Ana Mihaela Lungu

LOW FRICTION COATINGS PREPARED BY PLASMA ELECTRODE TYPE SPRAY GUN

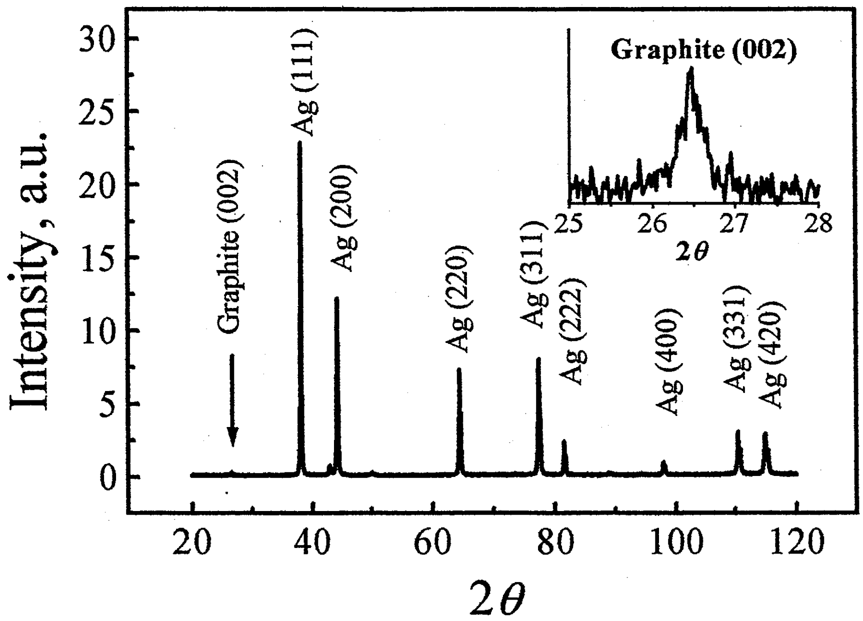


Fig. 4. XRD pattern of Ag/graphite coating deposited at 3 cm distance from the nozzle exit. The zoom part of the figure shows the characteristic peak ($2\theta$= 26.4 degree) of graphite (Graphite-2H, hexagonal)

**O. Fukumasa, K. Osaki and S. Fujimoto/ C.P.Lungu and Ana Mihaela Lungu**

**LOW FRICTION COATINGS PREPARED BY PLASMA ELECTRODE TYPE SPRAY GUN**

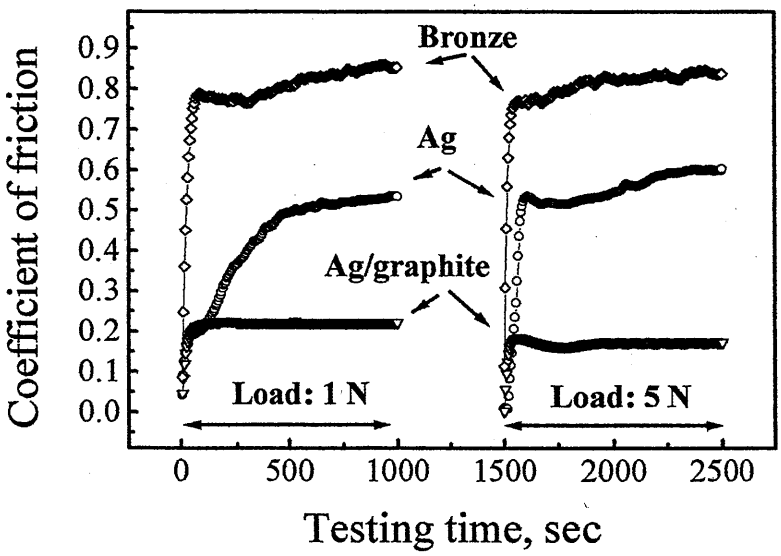


Fig. 5. Frictional characteristics of the Ag and Ag/graphite coatings prepared at 3 cm distance from the exit nozzle and bronze. In this case substrates were fixed.

**O. Fukumasa, K. Osaki and S. Fujimoto/ C.P.Lungu and Ana Mihaela Lungu**

**LOW FRICTION COATINGS PREPARED BY PLASMA ELECTRODE TYPE SPRAY GUN**