Vojnotehnicki glasnik/Military Technical Courier
ISSN: 0042-8469
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University of Defence
Serbia

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Vojnotehnicki glasnik/Military Technical Courier, vol. 65, núm. 3, 2017, pp. 662-672
University of Defence

VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2017, Vol. 65, Issue 3

PROPERTIES OF THE COATING DEPOSITED WITH THE DIFFUSION OF MO&O_2 OXIDIZED POWDER USING THE APS PROCESS

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http://dx.doi.org/10.5937/vojtehg65-11966

FIELD: Chemical Technology
ARTICLE TYPE: Original Scientific Paper
ARTICLE LANGUAGE: English

Summary:

Powder Mo&O_2 has an important role in the production of coatings with increased resistance to slide in conditions without the use of lubricants. Mo&O_2 coatings have the low coefficient of friction and good abrasion characteristics in mechanical stresses. For the purpose of producing coatings of high hardness, Mo&O_2 powder is plasma deposited with optimal parameters. The surface shape of oxide powder particles and the coating fracture surface are analysed by SEM, and the microstructure of layers is examined by light microscopy. The coating microstructure consists of Mo lamellae and MoO_3 and MoO_2 primary oxide thin films, which surround the Mo lamellae. The analysis of the obtained *results showed that the Mo&O_2 coating layers with the diffusion oxidized Mo particles have such a structure and mechanical characteristics which enable its application in working tools under the conditions of wear and sliding friction without lubricants.*

Keywords: particles, friction, deposits, property, powders, oxidizers, microstructures, lubrication, coatings.

ACKNOWLEDGEMENT: The author is thankful for the financial support from the Ministry of Education and Science of the Republic of Serbia (national project OI 174004).

Introduction

The $Mo\&O_2$ coating resistance to wear depends on the oxygen content and the applied kind of technological process of coating production (Mrdak, et al, 2005, pp.235-239), (Salhi, et al, 2005, pp.145–150). Molybdenum powders containing oxygen $Mo\&O_2$ can attain high hardness values. The content of oxygen in the plasma spray coating essentially depends on the applied gases and applied power devices. After the production of $Mo\&O_2$ coatings, the layers have sufficient concentration of oxygen which gives to oxides high hardness the values of which exceed 1000HV. Thus deposited coatings can increase fatigue strength to friction up to 120% in working tool surfaces, thus preventing loss of the material by friction. The friction that always occurs between two movable contact surfaces causes damage such as friction wear and friction fatigue. There are many research papers relating to the mechanisms of friction wear and friction fatigue. Modes of friction are standardized and used to study the behavior of different materials regarding the mechanism of friction wear (Vencl, et al, 2011, pp.1281-1288), (Mrdak, 2016a, pp.411-430), (Mrdak, 2016b, pp.949-965). By microscopic examinations, the authors (Chen, et al, 2007, pp.2132-2138), (Yongqing, et al, 2000, pp.231-245) found that Mo lamellae and MoO_2 and MoO_3 primary oxides from powder are present in the $Mo\&O_2$ coating. Oxides are present in the form of thin films that surround Mo lamellae. The MoO_2 oxide phase increases hardness but also brittleness which negatively affects the cohesive strength of lamellae (Modi, Calla, 2001, pp.480-486). The best structure is found in coatings where oxide films are continuously arranged along the coating and act as a lubricant while preventing metal contact and maintain a low coefficient of friction. The crystal structure of MoO_2 is monoclinic while α-MoO_3 and β-MoO_3 oxides are of orthorhombic and monoclinic structures (Jullien, et al, 1995, p.235). Tests of the $Mo\&O_2$ coating to wear determined that MoO_2 oxide in the coating reduces the coefficient of friction under 0:15, and MoO_3 oxide to the values in the range of 0.1 to 0.12 which is quite stable (Lyo, et al, 2003, pp.413-421), (Solak, et al, 2003, pp.713-719), (Suszko, et al, 2005, pp.319-324).

The aim of the study was to use atmospheric plasma for depositing $Mo\&O_2$ powder particles which will form hard slide-resistant coating layers. The paper analyzes the mechanical properties of micro hardness and the tensile bond strength as well as the microstructure on a light microscope and the morphology of powder particles and the coating fracture surface on the SEM. The analyses of the layers confirm the good mechanical and structural characteristics of Mo&O_2 coatings, which make them reliable in conditions of sliding friction without lubrication.

Materials and experimental details

The Mo&O_2 powder used in the experiment had an oxygen content of 3% made by the Amperite program arising from the HCST production. Figure 1 (SEM) shows the powder particles of sharp and rounded edges, with a range of grains of 5 - 45 μm.

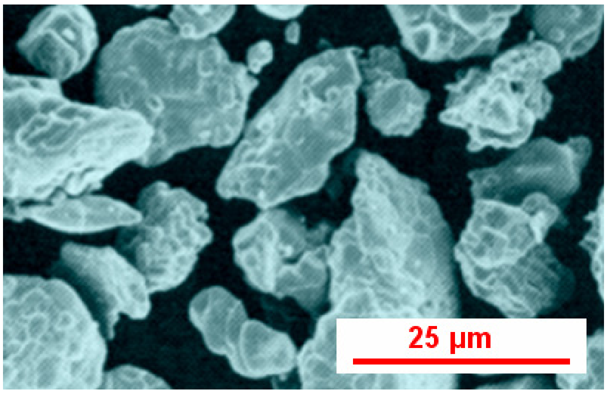

Figure 1 – (SEM) surface shape of Mo&O_2 powder particles
Рис. 1 – (SEM) Изображение поверхности частиц порошка Mo&O_2
Слика 1 – (SEM) Облик површине честица праха Mo&O_2

The substrate for deposited coatings was made of steel (X15Cr13 EN10027) according to the standard (Turbojet Engine, 2002). Microhardness was tested using the method of $HV_{0.3}$ with five reading values at the left end of the sample (A) in the middle (B) and at the right end (C) of the sample. The paper presents min. and max. $HV_{0.3}$ values. The bond strength testing was done on five samples by tensile testing at room temperature, and the average values are shown in the paper. The shape of the surface of powder particles and the coating fracture surface were analyzed by SEM.The microstructures of coating layers were analyzed with light microscope and the quantitative analysis of the average pore content in layers was carried out.

Mo&O_2 powder was deposited at atmospheric pressure by a SG-100 plasma gun with the use of a mixture of Ar and He gases and power up to 40kW. The Mo&O_2 powder disposition parameters are shown in Table 1. The coating was deposited in a thickness from 0.45 to 0.48 mm.

Table 1 – Powder deposition parameters
Таблица 1 – Параметры напыления порошка
Табела 1 – Параметри депозиције праха

Deposition parameters	Values
Plasma current, I (A)	600
Plasma Voltage, U (V)	31
Primary plasma gas flow rate, Ar (l/min)	48
Secondary plasma gas flow rate, He (l/min)	12
Carrier gas flow rate, Ar (l/min)	4.5
Powder feed rate (g/min)	35
Stand-off distance (mm)	100

Results and discussion

Figure 2 shows the values of the Mo&O_2 coating microhardness. At the left end of the sample, the coating microhardness was in the range of 968 - 1260$HV_{0.3}$, with the average value of 1114$HV_{0.3}$, the point (A). In the middle of the sample, microhardness is in the range of 972 - 1334 $HV_{0.3}$ with an average value of 1153$HV_{0.3}$, the point (B). At the point (C) which was located at the right end of the sample, microhardness covers the range of 934-1310 $HV0_{.3}$ with an average value of 1122$HV_{0.3}$.

The microhardness values were consistent with the oxygen content in the powder and with the primary oxide content in the coating. The microhardness values are quite high in comparison to conventional Mo coatings. Since oxides are present in the coating, the coating microhardness mean values are fairly uniform at all measuring points. This is the first indication that the oxide distribution in the coating layers is uniform (homogeneous). The coating had a mean value of the adhesion strength of 38MPa with a fracture mechanism at the substrate / coating interface.

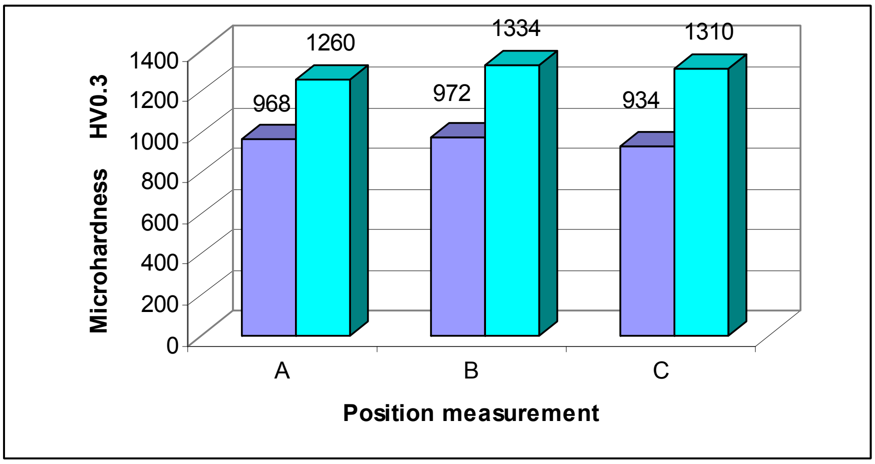

Figure 2 – The microhardness of the Mo&O2 coating, the measurement positions
Рис. 2 – Микротвердость покрытия Mo&O2 в точках измерения
Слика 2 – Микротврдоће превлаке Mo&O2 на позицијама мерења

Figure 3 shows the microstructure of the plasma spray Mo&O_2 coating recorded on a light microscope. At the substrate / coating interface, there are not any abnormalities that would reduce the impact on the coating adhesion strength. Light Mo lamellae are seen and between them dark and thin films of primary oxides are precipitated. At the inter-lamellar boundaries, there are black micro pores smaller than 10μm with a medium content in the coating of up to 3%.

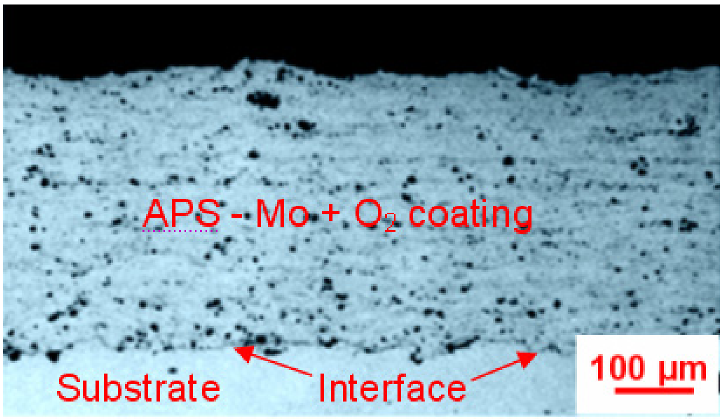

Figure 3 – Microstructure of Mo&O_2 coatings
Рис. 3 – Микроструктура Mo&O_2 покрытия
Слика 3 – Микроструктура Mo&O_2 превлаке

Figure 4 shows the microstructure of Mo&O_2 coatings at a higher magnification for the purpose of analysing the microstructure more clearly. The structure is the same as in Figure 3, except that dark oxide films can be more clearly noticed and that there are precipitates in the structure as a product of collisions of drops of molten powder particles with the substrate. There are neither cracks nor unmolten particles which could reduce the cohesive strength and coating resistance to friction fatigue. The coating primary phase is Mo with a centered cubic lattice in which are present the phases of MoO_2 oxide with the monoclinic lattice and MoO_3 oxide with the orthorhombic and monoclinic lattice (Chen, et al, 2007, pp.2132-2138), (Yongqing, et al, 2000, pp.231-245).

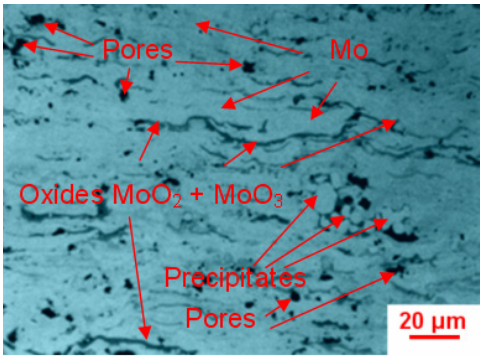

Figure 4 – Microstructure of Mo&O_2 coatings
Рис. 4 – Микроструктура Mo&O_2 покрытия
Слика 4 – Микроструктура Mo&O_2 превлаке

Figure 5 shows the Mo&O_2 coating surface recorded by electron microscope (SEM).

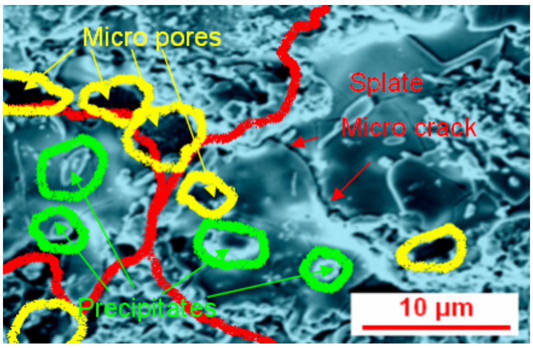

Figure 5 – (SEM) Surface of the Mo&O_2 coating
Рис. 5 – (SEM) поверхность Mo&O_2 покрытия
Слика 5 – (SEM) површина Mo&O_2 превлаке

On the surface it is possible to see two flattened disc-shaped particles, created by the collision of drops of molten powder particles with the substrate and by their subsequent cooling to the surface temperature. These discs are separated by red lines. This kind of deformation of liquid droplets in a collision with the substrate and solidification is an indicator of good inter-lamellar cohesive strength. On the formed discs, there are visibly noticeable micro cracks caused by the solidification of liquid drops. They cannot gather since the substrate was exposed to spreading due to the increase in temperature caused by the amount of heat carried liquid drops and transferred to the substrate. At the interface between the discs (lamellae), there are black micro-pores of less than 10μm in diameter. Micro pores of irregular shapes are highlighted in yellow. Fine deposits on the surface of the discs and the discs boundaries are marked in green.

Figure 6 shows the surface of an Mo& O_2 coating fracture recorded on the SEM. Thin lamellae with clearly distinguished interfaces can be seen on the coating fracture. The morphologies of micro pores and precipitates are also clearly visible.

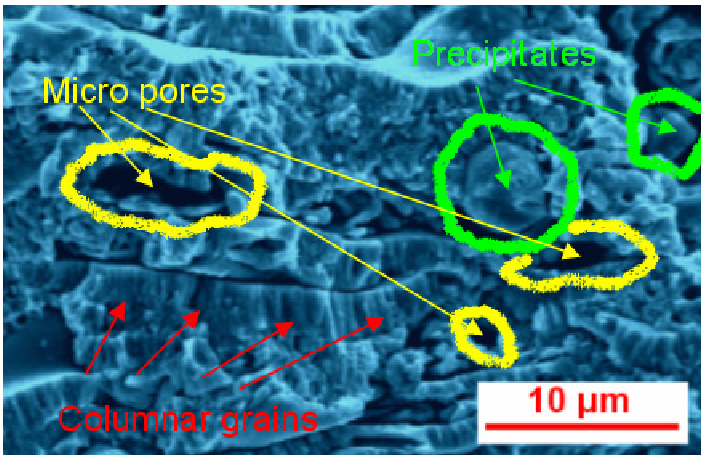

Figure 6 – SEM fracture of the Mo&O_2 coating surface
Рис. 6 – (SEM) Поврежденная поверхность покрытия Mo&O_2
Слика 6 – (SEM) површина лома превлаке Mo&O_2

The initial micro cracks occur in places with the highest stress. These places are interlamellar pores and interlamelar boundaries. Under the action of fracture forces on the substrate surface, initial micro cracks spread rapidly into macro cracks propagating vertically from the substrate surface through lamellae and micro pores up to the coating surface. The fracture shows clearly Mo lamellae with columnar grains directed normally to the metal substrate. Columnar metal grains originate from and are formed on the surfaces of the previously deposited drops of melted particles cooled to the temperature of the substrate with deposited layers (Vardelle, et al, 1994, pp.50–58). The fracture image shows precipitates and micro pores smaller than 10 μm. The coating fracture is brittle due to present oxides.

Conclusion

The paper presents the results of the analysis of the atmospheric plasma spray deposited Mo&O_2 coating with a thickness from 0.45 to 0.48 mm. Based on the analysis of the layers, the following conclusions have been derived.

The Mo&O_2 coating had a high average value of microhardness 1114 to 1153$HV_{0.3}$ and the adhesive bond strength of 38MPa due to the presence of oxide phases in the structure. The tensile testing showed the adhesive fracture mechanism.

The structure of the Mo&O_2 coating is lamellar, consisting of Mo lamellae and thin films of MoO_2 and MoO_3 primary oxides between the Mo lamellae. Among the Mo lamellae, there are micro pores of irregular shape up to 3%, and precipitates of less than 10μm in size.

With its mechanical and structural characteristics, the Mo&O_2 coating can significantly increase the resistance of working surfaces exposed to dry sliding friction, which is what they are intended for.

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СВОЙСТВА ПОКРЫТИЯ, НАНЕСЕННОГО ДИФФУЗИОННЫМ ОКСИДНЫМ ПОРОШКОМ $MO\&O_2$ МЕТОДОМ APS

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ОБЛАСТЬ: химические технологии
ВИД СТАТЬИ: оригинальная научная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

Применение порошка $Mo\&O_2$ играет важную роль в процессе нанесения покрытия с повышенной устойчивостью к скольжению в бессмазочных условиях. Покрытия $Mo\&O_2$ обладают низким коэффициентом фрикции и высоким пределом прочности при механическом напряжении. В целях достижения наибольшей прочности покрытия, порошок $Mo\&O_2$ наносится методом плазменного напыления, с учетом оптимальных параметров. Характеристики состояния поверхности частиц оксидного порошка и поверхности излома покрытия установлены SEM методом. А микроструктура слоев нанесенного покрытия испытана методом световой микроскопии. Микроструктура покрытия состоит из ламелей Mo и тонких оксидных прослоек MoO_2 и MoO_3 вокруг ламелей Mo. Анализ полученных результатов доказал, что слои покрытия $Mo\&O_2$ с диффузионными оксидными частицами Mo обладают структурой и механическими характеристиками, позволяющими нанесение данного покрытия на поверхности рабочих участков в условиях износа и скольжения при бессмазочном трении.

Ключевые слова: частицы, трение, нанесение, свойства, порошок, оксидаторы, микроструктуры, смазка, покрытие.

СВОЈСТВА ПРЕВЛАКЕ ДЕПОНОВАНЕ ДИФУЗИОНО ОКСИДИРАНИМ ПРАХОМ $MO\&O_2$ ПРИМЕНОМ APS ПРОЦЕСА

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Сажетак:

Прах $Mo\&O_2$ има значајну улогу у производњи превлака са повишеном отпорношћу на клизање у условима без примене *мазива. Превлаке Mo&O_2 имају мали коефицијент фрикције и добре карактеристике на хабање при механичким напрезањима. Ради производње превлака високе тврдоће, прах Mo&O_2 је депонован плазмом са оптималним параметрима. Карактеризација облика површине честица оксидног праха и површине прелома превлаке изведена је методом SEM, а микроструктура слојева применом светлосне микроскопије. Микроструктура превлаке састоји се од ламела Mo и танких филмова примарних оксида MoO_2 и MoO_3 које окружују ламеле Mo. Анализа добијених резултата показала је да слојеви превлаке Mo&O_2 са дифузионо оксидираним честицама Mo имају структуру и механичке карактеристике које омогућују њену примену на површинама радних делова у условима хабања и клизања трењем без мазива.*

Кључне речи: честице, трење, депозити, својства, прах, оксидатори, микроструктуре, подмазивање, превлаке.

Paper received on / Дата получения работы / Датум пријема чланка: 03.10.2016.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 16.01.2017.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 18.01.2017.