



Cold flame-sprayed and oil-impregnated porous metallic coatings

G. Kalácska^{a,*}, L. Fazekas^b, R. Keresztes^a, A. Tóth^c, J. Szépvölgyi^{c,d}

^a Institute for Mechanical Engineering Technology, Szent István University, Páter Károly u. 1, H-2100 Gödöllő, Hungary

^b Department of Mechanical Engineering, University of Debrecen, Ótemető u. 2–4, H-4028 Debrecen, Hungary

^c Institute of Materials and Environmental Chemistry, Chemical Research Center, Hungarian Academy of Sciences, Pusztaszeri út 59–67, H-1025 Budapest, Hungary

^d Research Institute of Chemical and Process Engineering, University of Pannonia, Egyetem u. 10, H-8200 Veszprém, Hungary

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ABSTRACT

Porous metallic coatings were prepared from three commercial alloy powders on 16MnCr5 steel by cold flame spraying. The mechanical characterisation of the coatings was performed by Vickers microindentation and debonding tests. Porosity was determined by image analysis of the optical micrographs of the polished cross-sections. The coatings were impregnated with motor oil 15W40 with the aim of preparing a lubricating system. The amounts of oil uptake and release by the coatings were determined under controlled conditions. The surfaces of the coatings were examined by X-ray photoelectron spectroscopy (XPS) and wettability studies. The amounts of oil uptake and release showed inverse relationship with the oxygen concentration at the surface and also with the Lifshitz-van der Waals component of surface energy. These relationships offer the possibility of controlling the lubrication properties of cold flame-sprayed and oil-impregnated porous metallic coatings.

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1. Introduction

Flame spraying belongs to the group of thermal spraying methods and is a well-established technique of surface engineering [1,2]. Its advantages include ease of application and low cost compared with other spraying processes. Flame spraying of coatings may be the final step in the production technology or may constitute itself a surface restoration technology. Applications include improvement of quality of machine components whose surface is subjected to severe tribological conditions [3], repair of worn shafts in sliding bearing areas [4] and corrosion protection [5]. With relatively low thermal input, the “cold” version of flame spraying can be performed [6]. It involves preheating the substrate up to about 100 °C and depositing the coating, during which the temperature of the sample does not exceed 250 °C. The application of the cold version of flame spraying is advantageous for the steel alloy substrate, because its structure and properties remain unchanged. The resulting coating has a porous structure, that can be impregnated by lubricating oil and the latter may be released slowly under load due to frictional and thermal effects. Decreased wear and expanded mild wear regime towards higher loads characterise the oil-impregnated porous coatings in sliding bearing applications [7].

The aim of this work was the characterisation of the oil uptake and release properties of cold flame-sprayed porous metallic coatings, because information is lacking on this subject. Since mechanical properties are also important in practical applications, characteristics like surface microhardness, in-depth microhardness and coating bond strength were also determined. The mechanical and oil impregnation properties of coatings prepared from three frequently applied commercial alloy powders were compared.

2. Experimental

2.1. Raw materials and coatings production

The substrate material was 16MnCr5 steel (Třinecké Železářny, Czech Republic). Disk-shaped samples with a diameter of 15 mm and thickness of 5 mm were machined, which were cleaned mechanically and washed by ethanol before spraying. To ensure acceptable bonding strength, an intermediate bonding layer from Xuper Ultrabond 5100 type alloy powder (Castolin Ltd., Hungary) was used. For coating purposes HardTec 19400 (high-alloy martensitic Cr steel), DuroTec 19910 (Ni–Cr alloy) and LubroTec 19985 (Ni–Cr alloy) type powders (Castolin Ltd., Hungary) were applied.

Cold flame spraying was performed by hand, applying a RotoTec-80 equipment (Castolin Ltd., Hungary). The main parameters were as follows: oxygen pressure = 4.0 bar, acetylene pressure = 0.7 bar, standoff distance = 180 mm, spraying angle = 90°. The samples were preheated by oxygen-rich flame to about

* Corresponding author. Tel.: +36 28 522 949; fax: +36 28 522 949.

E-mail address: kalacska.gabor@gek.szie.hu (G. Kalácska).

Table 1

Composition of the applied alloy powders as determined by EDX (m%).

Alloy	C	Ni	Cr	Fe	Mn	Mo	Co	B	Si	S	Al
Xuper Ultrabond		89.5				5.4					5.0
DuroTec	0.1	84.6	9.4	2.1	0.02	0.3	0.05	1.1	4.8	0.015	
HardTec	0.1	1.1	15.8	78.1	0.08			1.0		0.018	
LubroTec	0.03	74.7	15.4	8.4	0.11	0.1	0.1			0.01	

Table 2

Porosity and mechanical properties of the coatings.

Coating	Porosity (%)	Surface microhardness (μHV_{100})	Normal coating bond strength (MPa)	Shear coating bond strength (MPa)
DuroTec	23.1 $\pm$ 1.6	342.3 $\pm$ 1.8	9.1 $\pm$ 0.2	41.6 $\pm$ 1.7
HardTec	8.0 $\pm$ 0.6	335.4 $\pm$ 2.8	13.8 $\pm$ 0.9	52.6 $\pm$ 3.0
LubroTec	21.2 $\pm$ 1.0	198.1 $\pm$ 2.1	15.0 $\pm$ 1.0	60.5 $\pm$ 2.5

Table 3

Surface compositions of the coatings as determined by XPS (1st row: m%, 2nd row: at%).

Coating	O	C	Ni	Cr	Fe	Mo	B	Si	P
DuroTec	39.7	14.1	12.1	9.9		0.9	6.3	13.3	3.6
	47.4	22.4	4.0	3.7		0.2	11.1	9.1	2.3
HardTec	38.1	8.4	10.6	12.1	8.9	0.9	4.7	12.8	3.4
	51.0	15.0	3.9	5.0	3.4	0.2	9.4	9.8	2.4
LubroTec	30.4	12.5	27.5	18.1				11.5	
	45.6	25.0	11.2	8.4				9.8	

50–100 °C, as measured by a thermocouple fixed into the substrate in 2 mm depth and connected to a Spider 8 type measuring amplifier (Hottinger Baldwin Messtechnik, Germany), attached to a personal computer. At the applied standoff distance the flame did not reach directly the coated surface, thus no special action was needed to keep the flame spraying in cold regime. The thickness of the applied bonding layer was 0.2 mm (as measured by a PosiTector 6000 type eddy current coating thickness gage, DeFelsko Corp., USA), while that of the coating was 1.5 mm for samples prepared to tests of normal coating bond strength, and 2 mm for samples prepared to other studies.

2.2. Sample characterisation

The particle size of the starting powders was determined by vibrating sieving, and proved to be in the range between 20 and 80 μm .

Energy-dispersive X-ray analysis (EDX) of the alloy powders was performed by a JEOL JSM-35C type scanning electron microscope equipped with an EDAX 711 type energy-dispersive X-ray analyzer (Japan Electro Optics Laboratory, Japan). The operating conditions were as follows: voltage = 25 kV, electron take-off angle = 28°, sample tilting = 0°. The FDEM software with the ZAF correction was used for the evaluation of results.

Microindentation of coatings was performed by a Neophot-2 microindenter coupled with a metallic microscope (Carl Zeiss GmbH, Germany). The Vickers type hardness was determined applying a loading mass = 100 g and an image magnification = 500 $\times$. The same magnification was used for taking optical micrographs of the polished cross-sections of the coatings. The porosity was determined by digital image processing of these micrographs (as porosity area in % of total surface area, by the research software developed at the Institute of Engineering Informatics, SZIU), based on the average of nine parallel measurements.

The normal coating bond strength ($R_{\perp}$) was determined by an Instron 5581 tensile test machine (Instron, UK) and the method and holding jig of Nádasi [8]. According to this method, a cylindrical hole is drilled from the side of the sample holder, reaching the substrate–coating interface, and a cylindrical pin is used to apply a controlled load to detach a disk-shaped piece of coating. The shear coating bond strength ($R_{\parallel}$) was determined according to the DIN 50161 [9] standard, applying a ZD20 testing machine (Werkstoffprüfmaschinen, Germany). In evaluating the results, confidence intervals $\pm 2\sigma = 4\sigma$ were used (where σ is the standard deviation), corresponding to 95% probability of the true value being within that interval in case of normal distribution.

For studying oil uptake and release, thick-wall tube type samples from 16MnCr5 steel with dimensions $\varnothing 35/26 \times 45$ mm were

Table 4Reference peak position values for the components of the Ni 2p_{3/2}, Fe 2p_{3/2} and Cr 2p_{3/2} peaks.

Peak	Chemical state	Peak position (eV)	References
Ni 2p _{3/2}	Satellite	861.0	[13]
	Ni ₂ O ₃	855.7–857.3	[12]
	Ni(OH) ₂	855.5–855.6	[13,14]
	Ni ⁰	852.7–853.0	[13,14]
Fe 2p _{3/2}	FeOOH	711.8	[14]
	Fe ₂ O ₃	710.9	[14]
	FeO	709.4	[14]
	Fe ⁰	706.7	[14]
Cr 2p _{3/2}	CrO ₃	579.8	[14]
	Cr(OH) ₃	577.3	[14]
	Cr ₂ O ₃	576.8	[14]
	Cr ⁰	574.3	[14]

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