

**Szent István University**

**CONNECTION BETWEEN THE TECHNOLOGY AND THE PROPERTIES  
OF COLD FLAME-SPRAYED POROUS METALLIC COATINGS**

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## 1. INTRODUCTION, GOALS

### 1.1. Actuality of theme

Flame spraying belongs to the group of thermal spraying methods and constitutes a well-established technique of surface engineering. Its advantages include ease of application and low cost compared with other spraying processes. With relatively low thermal input, its "cold" variant can be performed, which involves preheating the substrate up to about 100 °C and deposition of coating, whereas the temperature of the system does not exceed 250 °C.

In spite of the relatively mild conditions, good bonding between the substrate materials and a wide range of alloys can be achieved, especially if intermediate bonding layers are applied. Cold flame spraying of coatings may be the final step in the production technology or may constitute itself a surface restoration technology. Applications include corrosion protection, repair of worn shafts in sliding bearing areas, etc. In agricultural engineering the technology is also used for shaft renewing typically operating in hostile environment and the replace with new parts means extra costs.

Cold flame-spray technology was investigated in many other areas of mechanical engineering during the past decades and gained overall acceptance in the field of vehicle parts, turbine elements, aviation...etc. However the technological steps are clearly described in the literature and detailed suggestions – regarding the powders, the spraying guns, part preparation and spraying methods - are available from different producers some lack of the technology was found that established my research program.

### 1.2 The aim and tasks of the research work

According to the literature study and my personal experiences in the field of cold flame-spraying technology I set the following aims: to study the conditions of achieving self-lubrication effect, applying a combination of cold flame spraying of porous metallic coatings and impregnation of coatings with lube oil, where the latter may be released slowly under load due to frictional and thermal effects. The performance of three different commercial alloy powders was compared, which are applied frequently in cold flame spraying to improve surface mechanical properties as it follows:

- HardTec 19400 – hard coating, protection against abrasive effects (determining are: Fe 78,1 %, Cr 15,8%, Ni 1,08%) further „HardTec” composition,
- LubroTec 19955 – excellent sliding requirements (determining are Ni 74,7%, Cr 15,42%, Fe 8,35%) further „LubroTec” composition.

- DuroTec 19910 – tough and hard coating utilization of the dynamic loadability (determining are: Ni 84,61%, Cr 9,35%, Si 4,8%, Fe 2,05%, B 1,1%) further „DuroTec composition”.

Special attention was paid to the influence of standoff spraying distance (SOD), because flame spraying is usually performed by hand, during which the normal SOD, proposed by the manufacturer, cannot be kept precisely. At the same time, SOD may have strong influence on the performance of spray-deposited coatings thus the mechanical behaviour of layers obtained with different SOD was also investigated. The topic of oil-impregnated porous metallic coatings can be related to the adhesively prepared and oil-imbibed advanced wooden bearings, applied in agricultural machinery like combine harvesters, field machines for arable farming, etc.

The self-lubrication ability of the porous coatings was tested with the measurements of oil uptake and release and was analyzed with the change of surface energy components and the final chemical composition of the surface.

## 2. MATERIAL AND METHOD

Porous coatings were prepared from HardTec 19400, DuroTec 19910 and LubroTec 19955 type metallic alloy powders on 16MnCr5 steel by cold flame spraying, applying standoff distances (SOD) ranging from 100 to 260 mm. Compactness and in-depth distribution of microhardness were studied by Vickers microindentation measurements. Coating bond strength was examined by debonding tests. Energy-dispersive X-ray analysis (EDX) was used for elemental analysis of the alloys. Scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS or ESCA) and contact angle measurements were applied for surface characterization. The coatings were impregnated with motor oil 15W40 with the aim of preparation of a self-lubricating system. The oil uptake and release were investigated under controlled conditions.

### 2.1 Materials

The substrate material was 16MnCr5 steel (Třinecké Železárny, 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. For the preparation of the intermediate bonding layer Xuper Ultra Bond 5100 type alloy powder (Castolin Eutectic) was used. For coating purposes HardTec 19400, DuroTec 19910 and LubroTec 19955 type alloy powders (Castolin Eutectic) were applied. Hereinafter, these powders and the coatings made from them will be denoted briefly as HardTec, DuroTec and LubroTec.

### 2.2 Cold flame spraying

It was performed by hand, applying a RotoTec-80 equipment (Castolin Eutectic). The main parameters were as follows: oxygen pressure = 4.0 bar, acetylene pressure = 0.7 bar, standoff distances = 100, 140, 180, 220 and 260 mm, spraying angle = 0°. The samples were preheated by oxygen-rich flame to about 50-100 °C. The thickness of the bonding layer was 0.2 mm, while that of the coating was 1.5 mm for samples prepared to tests of normal component of coating bond strength, and 2 mm for samples prepared to other studies.

### 2.3 Scanning electron microscopy and energy-dispersive X-ray analysis

The polished cross-sections of the substrate-coating systems were studied by a JEOL JSM-35C type scanning electron microscope. EDX analysis was done with an EDAX 711 type energy-dispersive X-ray analyzer. 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.

#### **2.4 Microindentation**

Microindentation was performed on the polished cross-sections of the substrate-coating systems. A Neophot-2 metallic microscope coupled with a microindenter (Carl Zeiss GmbH, Germany) was used. The Vickers type hardness was determined applying a loading mass = 100 g and an image magnification = 500 $\times$ . The cracking behaviour of the coatings was studied by visual examination of the indents at an image magnification = 100 $\times$ .

#### **2.5 Coating bond strength**

For determination of the normal component of coating bond strength ( $R_{\perp}$ ), a tensile machine and the method and holding jig of Nádasi were used. 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 component of coating bond strength ( $R_{\parallel}$ ) was determined by the method of Metco Co., with the specimen preparation according to the DIN 50161 standard, applying a ZD20 type testing machine. In evaluating the results, confidence intervals  $\pm 2\sigma = 4\sigma$  were used (where  $\sigma$  is the standard deviation), corresponding to 95% probability of the true value being within that interval in case of normal distribution.

#### **2.6 Oil uptake and release**

For these studies, thick-wall tube type samples from 16MnCr5 steel with dimensions  $\varnothing 35/26 \times 45$  mm were machined and flame spray-coated to a thickness of 1.5 mm. The mass of coating was determined by  $10^{-5}$  g accuracy. The method of Pellényi was applied to determine the oil uptake and release. The samples were immersed in 15W40 motor oil, heated from 20 to 80 °C in 2h, kept at this temperature for 4h, wiped with a cloth to dry and weighted to determine the oil uptake. Then the samples were cooled down to 20 °C in 4h, kept at this temperature for 2h, wiped with a cloth to dry and weighted again to determine the oil release. To obtain specific values, oil uptake and release were related to the mass of the dry coating. Five parallel measurements were performed for each case and the average values were calculated. In evaluating the results, confidence intervals  $\pm 2\sigma = 4\sigma$  were used also here.

### **2.7 X-ray photoelectron spectroscopy**

XPS studies were done by a Kratos XSAM 800 spectrometer, using Mg K $\alpha$  radiation and fixed analyzer transmission mode (80 and 40 eV pass energies for the wide scan and detailed spectra, respectively). The spectra were referenced to the C 1s line (binding energy, BE = 285.0 eV) of the hydrocarbon type carbon. Data acquisition and processing were performed with the Kratos Vision 2 program.

### **2.8 Wettability**

Samples used for wettability measurements were slightly post-flame-treated to close the surface pores and smoothen the surface. Contact angle measurements were done by the static sessile drop method at 23 °C, with double distilled water and diiodomethane (Sigma-Aldrich, Reagent Plus 99% grade), applying the SEE System apparatus (Advex Instruments). Each result of contact angle is an average of 5 measurements, performed always on dry parts of the samples. The surface free energy and its polar and dispersive components were calculated by the method of Owens and Wendt.

### 3. RESULTS AND DISCUSSION

#### 3.1 Chemical composition and particle size of the powders

The manufacturer gives only indicative values about the chemical compositions of the alloys, therefore these were analyzed by EDX. The results are reported in Table 1. The characteristic components are Cr, Ni and Fe (in strongly varying proportions), but the following constituents could also be identified: C, Mn, S for each alloy, Mo and Co for DuroTec and LubroTec, B for DuroTec and HardTec, and Si for DuroTec. The alloy for the bonding layer (Xuper Ultra Bond 51000) contained Ni, Mo and Al.

The particle size of the starting powders was between 20 and 80  $\mu\text{m}$ , as determined by vibrating sieving.

Table 1. Composition of the applied alloys as determined by EDX (m%)

Alloy	C	Ni	Cr	Fe	Mn	Mo	Co	B	Si	S	Al
Xuper Ultra Bond 51000		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	

#### 3.2 Compactness of coatings, crack initiation and in-depth distribution of microhardness

The SEM images taken on the polished cross-sections of the coatings, flame-sprayed at the normal SOD = 180 mm, clearly demonstrate a porous structure (Fig.1).

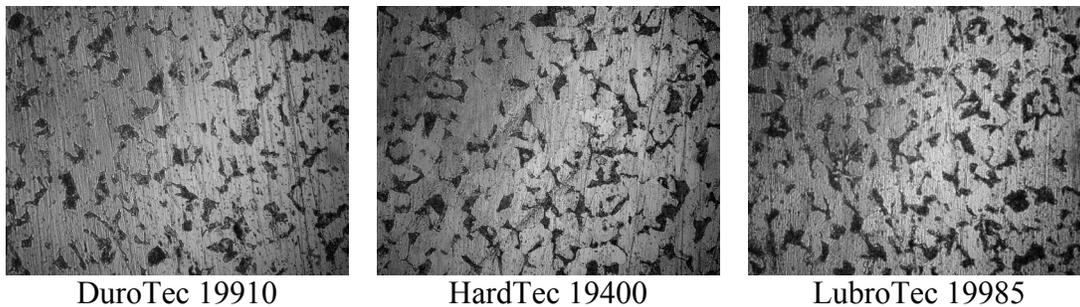


Figure 1. SEM images, 500x

The compactness of each coating was checked by measuring the Vickers microhardness on the polished cross-sections and comparing the values obtained with the lower limiting values specified as acceptable. The latter ranged between 340 and 350  $\mu\text{HV}_{100}$  for DuroTec, 332 and 345  $\mu\text{HV}_{100}$  for HardTec, and 190 and

200  $\mu\text{HV}_{100}$  for LubroTec coating. Table 2 demonstrates the results of comparison, where the positive sign denotes acceptable values, while the digital values are the percentages of the corresponding lower limiting values. Coatings prepared at SOD = 180 and 140 mm have acceptable compactness. Decreased compactness occurs, however, at lower and higher values of SOD.

Table.2. Compactness of the coatings at various standoff distances as determined by Vickers test

Coating	Decreased standoff distance		Normal standoff distance	Increased standoff distance	
	100 mm	140 mm	180 mm	220 mm	260 mm
DuroTec	90%	+	+	95%	85%
HardTec	95%	+	+	95%	90%
LubroTec	90%	+	+	+	95%

+ acceptable

Table 3 demonstrates the results of cracking studies of the coatings, showing that crack initiation occurs only at the ends of the intervals of SOD.

Table 3. Cracking behavior of the coatings at various standoff distances

Coating	Decreased standoff distance		Normal standoff distance	Increased standoff distance	
	100 mm	140 mm	180 mm	220 mm	260 mm
DuroTec	–	+	+	+	–
HardTec	+	+	+	+	–
LubroTec	–	+	+	+	+

+ no cracking, – crack initiation

The in-depth distribution of microhardness was studied by microindentation measurements along the polished cross-section of the flame-sprayed coatings. The results are shown in Fig. 2. The vertical line at zero thickness corresponds to the substrate/coating interphase. It can be seen that at normal SOD, microhardness is uniform throughout the coating layer, it decreases only near the interphase (Fig. 2, top). At SOD smaller (Fig. 2, middle) and higher (Fig. 2, bottom) than normal, microhardness tends to decrease and scatter tends to increase. This is in agreement with the results of studies on compactness, described above. DuroTec and HardTec proved to be harder than LubroTec, while the microhardness values of DuroTec and HardTec were similar. The increased hardness of the latter two coatings can be explained by the presence of C and B (and Si in DuroTec), while B and Si are absent and C is present in decreased amount in the less hard LubroTec (Table 1).

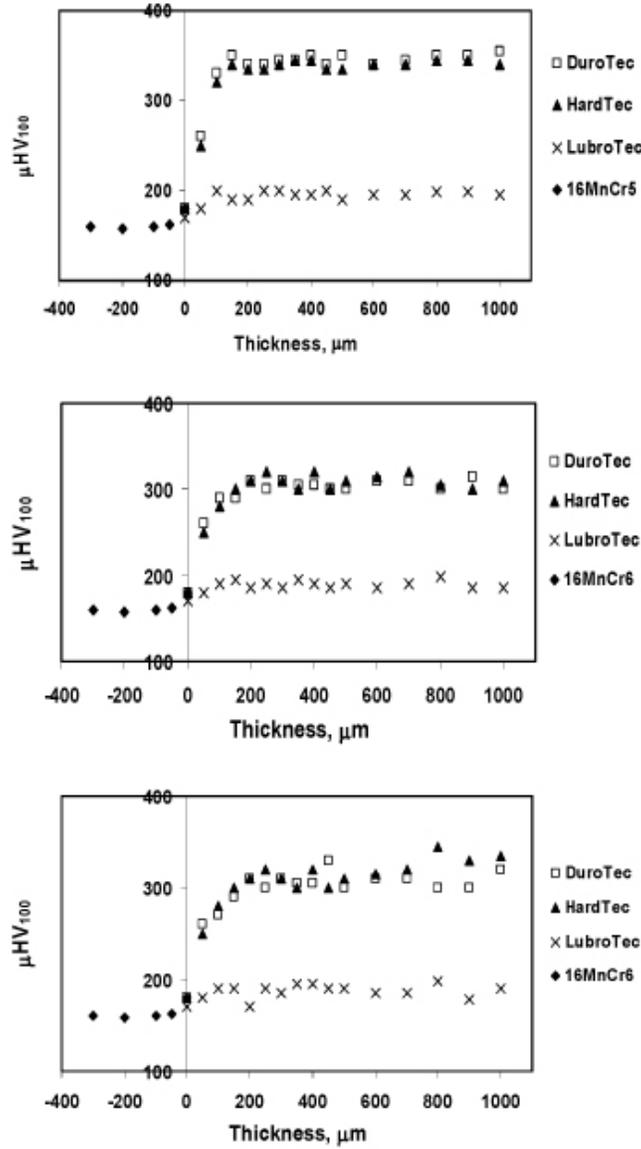


Figure 2. In-depth distribution of microhardness, SOD from top to bottom 180 mm, 100 mm, 260 mm

### 3.3 Coating bond strength

The dependence of normal component of coating bond strength ( $R_{\perp}$ ) on the standoff distance for the various coatings is shown in Fig. 3. The evolution of  $R_{\perp}$  proved to be sensitive to SOD and depended on the type of alloy applied.  $R_{\perp}$  for DuroTec (compared hereinafter to the base value obtained at normal SOD), decreased upon increasing SOD, while it did not change much upon decreasing SOD.  $R_{\perp}$  for HardTec decreased upon increasing SOD, but increased upon decreasing SOD. A completely different trend was observed for the LubroTec

coating:  $R_{\perp}$  decreased strongly upon decreasing SOD, and appeared to decrease slightly upon increasing SOD.

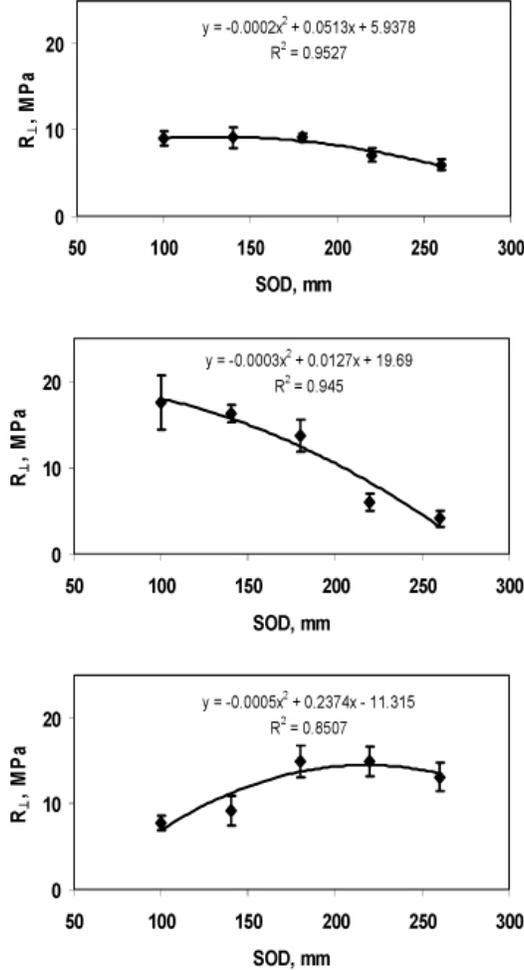


Figure 3. Normal component of coating bond strength,  $R_{\perp}$   
From top to bottom: DuroTec, HardTec, LubroTec

This is in agreement with the above results, according to which the composition and hardness of LubroTec differ strongly from those of the other two alloys. The evolution trends of  $R_{\perp}$  versus SOD can be fitted by second order polynoms. Comparing the three alloys, at and near the normal SOD, HardTec and LubroTec seem to have similar  $R_{\perp}$  values ( $\sim 14$  MPa), while the corresponding value for DuroTec is smaller ( $\sim 9$  MPa). This is most likely connected to the hindered diffusion of B and Si due to the relatively low temperature of the cold flame-sprayed system.

Upon shear tests, no detectable scratch tracks remained on the samples, the coating was always sheared off in a form of a 2 mm thick single cylindrical piece, and shear took place inside the bonding layer. The dependence of shear component of

coating bond strength ( $R_{\parallel}$ ) on the standoff distance is shown in Fig. 4. According to these results,  $R_{\parallel}$  was sensitive to SOD and depended on the type of alloy applied, similarly to the case of the normal component. In particular, for HardTec and DuroTec, deviation from the normal SOD was less detrimental in case of decreased SOD, while the opposite trend was observed for LubroTec.

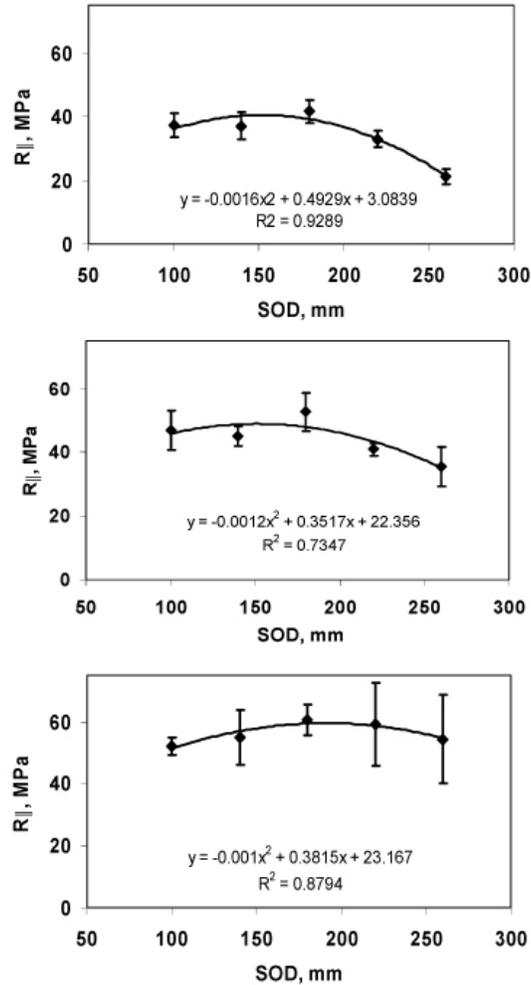


Figure 4. Shear component of coating bond strength,  $R_{\parallel}$   
From top to bottom: DuroTec, HardTec, LubroTec

The maximum achievable values of  $R_{\parallel}$  were about 40, 50 and 60 MPa for DuroTec, HardTec and LubroTec, respectively. Such a trend can be explained by the hindered diffusion of B in HardTec and of B and Si in DuroTec upon cold flame spraying. Comparing the normal and shear components of coating bond strength, the normal component was always much smaller than the shear one: the values of  $R_{\parallel}/R_{\perp}$  proved to be about 4.4, 3.4 and 4 for DuroTec, HardTec and LubroTec, respectively. As mentioned above, flame spraying is usually performed by hand, during which the normal SOD cannot be kept precisely. Therefore, the information presented in Figs. 3 and 4 can be of great practical importance.

### 3.4 Oil uptake and release, surface composition and wettability

As stated in the Introduction, the main objective of this work was to study the conditions of achieving self-lubrication effect by lube oil impregnation of the flame-sprayed coatings. Therefore, the oil uptake and oil release were examined for samples prepared at various standoff distances, under controlled conditions, as described in the Experimental part. The results are reported in Fig. 5.

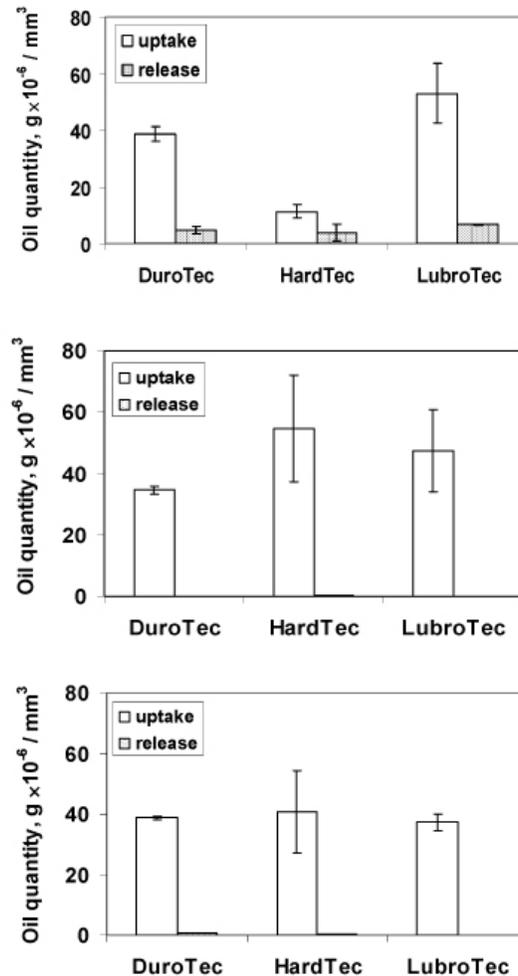


Figure 5. Oil uptake and release  
SOD from top to bottom 180 mm, 100 mm, 260 mm

It can be seen that in case of the normal SOD (Fig. 5, top), the order of increasing oil uptake for the coatings is: HardTec < DuroTec < LubroTec. Oil release changes in the same order. For SOD smaller (100 mm, Fig. 5, middle) and higher (260 mm, Fig. 5, bottom) than normal, oil uptake may be increased in case of HardTec. However, the scatter becomes high, reflecting an uncertainty of technology under these conditions. More importantly, oil release decreases strongly for SOD values

other than 180 mm. In conclusion, oil release, essential for self-lubrication, is the highest for the LubroTec coating at SOD of 180 mm.

The surfaces of the flame-sprayed coatings prepared at normal SOD were analyzed by XPS. Samples prepared with other SOD values were left out of consideration, due to the essential loss of lubrication property. Table 4 shows the calculated surface compositions in mass percents, for easy comparison with the corresponding alloy compositions (Table 1). It is clearly seen that the surface composition differs strongly from that of the bulk. In particular, the high amount of surface O reflects strong surface oxidation, in agreement with the oxidized chemical states of the surface elements (not shown). In addition, definite amounts of P for DuroTec and HardTec, and Si for HardTec and LubroTec were detected, which could be present in bulk in traces only. Regarding the main metallic components, the bulk and surface concentrations of Cr are similar, but a clear depletion in the surface Fe-content can be observed. The surface Ni/Cr ratio decreased for DuroTec and LubroTec and increased for HardTec. Strong surface enrichment of B (for DuroTec and HardTec), Si (for DuroTec) and C (for each coating) can be observed. Segregation and eventual evaporation may contribute to the deviation of surface composition from that of the bulk.

Table 4. Surface composition of the coatings prepared at normal standoff distance (180 mm) as determined by XPS (m%)

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
HardTec	38.1	8.4	10.6	12.1	8.9	0.9	4.7	12.8	3.4
LubroTec	30.4	12.5	27.5	18.1				11.5	

Coatings prepared at the normal SOD were characterized also by wettability measurements. The values of contact angle for water and diiodomethane, together with the calculated surface energies and their polar and dispersive components, are reported in Table 5. This shows that the total surface energy of the coatings increased in the order LubroTec < HardTec < DuroTec, and that surface energy is dominated by the polar component for LubroTec and by the dispersive component for DuroTec and especially for HardTec.

Table 5. Values of contact angles, surface energy and its components, obtained for the flame-sprayed coatings at normal standoff distance (180 mm)

Coating	Water contact angle (deg)	Diiodomethane contact angle (deg)	Surface energy mJ/m <sup>2</sup>	Polar component mJ/m <sup>2</sup>	Dispersive component mJ/m <sup>2</sup>
DuroTec	50±2	30±7	57.0	14.4	42.7
HardTec	86±7	≈0.5	52.0	1.2	50.8
LubroTec	106±7	36±6	41.3	41.1	0.2

Fig. 6 depicts the dependence of oil release on the components of surface energy of the coatings. The lines are drawn only to guide the eye. It is clearly seen that oil

release increases with the increase of the polar component and with the decrease of the dispersive component. Indeed, it is the best performing LubroTec coating, which has the highest polar component and the lowest dispersive component of surface energy (Table 5). It implies that LubroTec has the least oleophilic surface from among the coatings studied. This property of LubroTec can be explained by its surface composition (Table 4): this coating has the highest surface concentration of the alloy-forming metallic constituents and the lowest surface concentration of nonmetallic (high electronegativity) components.

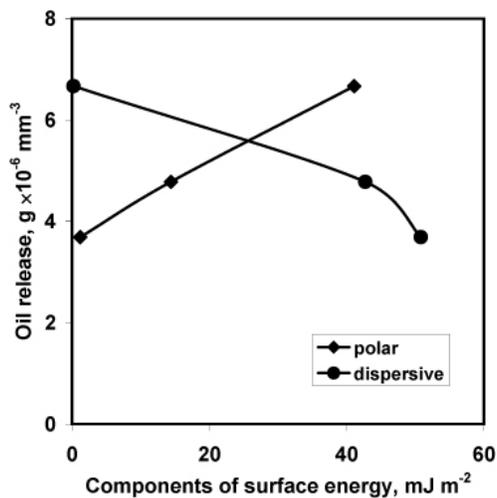


Figure 6. Oil release on the components of surface energy

#### 4. NEW SCIENTIFIC RESULTS

Conditions:

I have selected three characteristic powder-alloys for the extreme technological application fields of the cold flame-spraying metal power spraying technology to be characteristically distinguished by their chemical compositions.

- HardTec 19400 – hard coating, protection against abrasive effects (determining are: Fe 78,1 %, Cr 15,8%, Ni 1,08%) further „Hard Tec” composition,
- LubroTec 19955 – excellent sliding requirements (determining are Ni 74,7%, Cr 15,42%, Fe 8,35%) further „LubroTec” composition.
- DuroTec 19910 – tough and hard coating utilization of the dynamic loadability (determining are: Ni 84,61%, Cr 9,35%, Si 4,8%, Fe 2,05%, B 1,1%) further „DuroTec composition”.

By keeping the technical literature and manufacturer technological parameters I have evaluated the test results in the function of changing one technological characteristic – the standoff spraying distance (SOD) -. The generally suggested 180 mm distance I extended to 220 and 260, as well as 140 and 100 mm spraying distance. Based on these I have drawn up the followings concerning the strength, oil adsorption – and emission as well as surface energy.

No.1 thesis

I have established with the density test based on Vickers – inspection (common evaluation of surface and sectional hardness values) that the density of porous layer sprayed is insensitive to the spraying distance, only at the extreme values of the spraying distance could be experienced 5-10% hardness decrease. This result doesn't correlate with the results of porosity – change based on the digital exposure processing so the hardness decrease is first of all the common effect of other factors (grain shape -, dimension, grain surface adhesion..etc.) influencing the load-bearing capability of granular structure. I have further established that changing the spraying distance doesn't increase the danger of cracking.

No.2 thesis.

I have established that in case of a given spraying distance taken up, the micro-hardness distribution interpreted in the section of sprayed layer is constant on the 180 mm spraying distance, the  $\Delta\mu\text{HV}$  zone (the range of hardness values) <10% as compared with the maximum  $\mu\text{HV}$  value measured. The  $\Delta\mu\text{HV}$  zone increases 10-20% depending on the material at the extreme values of the spraying distance at determined trends, nevertheless the average hardness decreases according to the drawn up in the No. 1. thesis.

The degree of the reduction was more significant at metal powder alloys containing Ni, Cr, Si and Fe components.

No. 3 thesis.

Based on the normal directional bond strength tests carried out with the Nádasi – method I have established that the spraying distance influences the bond strength with different degree and character in case of various powder alloys according to the followings:

3/a. The normal directional bond strength of the sprayed layer made of “DuroTec composition” powder alloy is sensitive to the increase of spraying distance. The increase of the distance as compared with the 180 mm optimum spraying distance results strength decrease, the trend can be approximated with quadratic polynome:

$$y = -0,0002x^2 + 0,0513x + 5,9378$$

The reduction of the spraying distance doesn't change in average the bond strength but the increased measuring results' standard deviations indicate the uncertainty of the technology in case of reduced spraying distance. The difference from the 180 mm spraying distance is less disadvantageous if it goes with reduction of spraying distance.

3/b. The average values of the bond strength in normal direction sprayed with “HardTec composition” coating slightly increased together with the standard deviation of the measuring results in case of reducing the spraying distance. The increase of the spraying distance reduces significantly the bond strength in normal direction. The trend can be approximated with quadratic polynome:

$$y = -0,0003x^2 + 0,0127x + 19,69$$

I defined the interval of the standard deviation distance which is a value between 140-180 mm at “Hard Tec composition” powder from the bond strength in normal direction standpoint.

3/c. The bond strength in normal direction of the sprayed layer with “LubroTec composition” powder alloy in the function of spraying distance results opposite trend with the HardTec and DuoTec compositions. The strength of the sprayed layer with “LubroTec composition” strongly decreases in case of reducing the spraying distance, while increasing the spraying distance reduces less the bond strength. The trend can be approximated with quadratic polynome:

$$y = -0,0005x^2 + 0,2374x - 11,315$$

The internal of the standard deviation distance can be interpreted, its suggested value is between 180-220 mm.

No.4 thesis.

I have proved with my METCO-type measurings of shearing bond strength that the spraying distance influences the shearing bond strength in different degree in case of an three powder-alloys, but this influencing effect doesn't agree with the trends of bond strength in normal direction.

4/a. The shearing bond strength of the “DuroTec” layer is sensible to the increasing of the spraying distance. The distance increase as compared with the optimum 180

mm spraying distance results strength decrease which can be approximated with quadratic polynome:

$$y = -0,0016x^2 + 0,4929x + 3,0839$$

The reduction of the spraying distance reduced hardly 10% in average the bond strength, the standard deviation of the measuring results are nearly identical (relative standard deviations 4-5,5%). I have established that the optimum spraying distance within interval the shearing bond strength of the layers sprayed with "DuroTec composition" powder alloy is 4,4 times higher than the bond strength in normal direction. This rate is smaller in case of other spraying distances.

4/b. The average values of shearing bond strength of sprayed layer with "HardTec composition" coating decreased in small degree with hardly 5% in case of reducing the spraying distance, the standard deviation of values measured didn't change unfavourably, too. The increase of spraying distance reduces the shearing bond strength. The trend can be approximated with quadratic polynome:

$$y = -0,0012x^2 + 0,3517x + 22,356$$

The interval of the suggested optimum spraying distance is 150-190 mm at this powder alloy.

4/c. The shearing bond strength of the "Lubro Tec" layer in the function of spraying distance resulted opposite trend with the "HardTec" and "DuroTec" coatings, which can be approximated by quadratic polynome:

$$y = -0,001x^2 + 0,3815x + 23,167$$

The shearing bond strength of the "LubroTec composition" coating changes in more sensitive way (more strongly decreases) to the reduction of spraying distance as in case of increasing the spraying distance. Concerning the shearing bond strength it is suggested to keep the 180 mm spraying distance.

No.5 thesis.

I have established based on my measurements comparing the strength properties of the three powder alloys that in case of "DuroTec composition" coating the values of lower shearing bond strength measured – similarly to the strength values in normal direction – prove that diffuse effect of silicium and boron added beside the main alloys (C, Ni, Cr, Fe) deciding the characteristics of powder alloys doesn't assert or asserts only poorly in case of cold metal powder spraying (flame spraying).

The measuring results proved that in case of cold flame spraying the diffusion capability of B and Si strongly influenced and limited by the material and technological system, by the alloy structure and spraying method.

No.6 thesis.

I have proved with XPS-measurements that the chemical composition of the surface after spraying differs from the original powder compositions having effect on the lubricant adsorption – and emission capacity. I established that the surface becomes barren in Fe while enrichment happens in B, C and Si as a result of cold flame

spraying at the powders examined. This proves furthermore also the impediment of the B and Si improving role of the original bond strength drawn up in No.5 thesis.

No.7 thesis.

I have established that the lubrication oil emission capacity of the porous layers sprayed is the greatest in case of normal spraying distance, changing the spraying distance reduces drastically the oil emission capacity. I have proved with my measurings that the oil emission capacity increases with the increase of the polar component of the surface energy and with the decreases of dispersive component. The LubroTec layer guaranteed the greatest oil emission which has got the greatest polar energy component and has got the smallest dispersive energy component, further more has got the highest rate of metal components.

## 5. CONCLUSIONS, SUGGESTIONS

It came to light from studying the technical literature that the manufacturers enclose detailed recommendations to the different powder alloys concerning the application fields and the characteristics of probable coatings (for example DurOptic program).

Concerning the practical application it is an outstandingly important fact that the spraying of powders takes place mainly with manual technology, surely this ensures the quickness, elasticity for the process. The manual process has always got subjectivity and from this results that in case of at most powder compositions the suggested spraying distance as an absolute data can't be kept.

I have selected three, basically different powder alloys representing various powder groups from the powders suggested for cold flame spraying in the commercial turnover, suggested for the most extreme application of parts sprayed with cold technology and they function as sliding surface, too.

- During my research-work I have examined the complex effect of the spraying distance to the coating characteristics in case of three powder compositions typically used for cold flame spraying which summary can be found in Table 5.1.

It can be drawn up concerning the Table 5.1 that the effect of changing the suggested normal spraying distance:

- is not significant concerning the micro-hardness and crack forming,
- based on bond strength standpoint it can be accepted within certain limits,
- it can't be accepted concerning emission capacity.

The summary in Table 1. presents the more exact planning of the application of the cold flame spraying technology (HardTec 19400, LubroTec 19985, DuroTec 19910) and the extension of adaptability of porous surface coatings produced in the engineering practice.

## 6. SUMMARY

The technology of surfaces produced with thermal spraying underwent on spectacular development in the past decades and the development goes on nowadays, too. The method is also used at such advanced technical application as renewing, repairing parts of jet propelled power plant. I have put the emphasis on my research work, to the cold flame spraying that is on the examination of surface coatings with porous structure. The cold flame spraying is a wide – spread method renewing shafts worn in normal work renewing sliding bearing surfaces, or other sliding surfaces well identifiable. The main advantage of the technology is it can be also used in case of alloyed shafts as avoiding heat effect higher than 200-300<sup>0</sup>C the get hardening, the texture change can be avoided.

I have selected three basically different powder alloys representing various powder groups suggested for cold flame spraying in my research program suggested for the most extreme application of parts sprayed with cold technology and they function as sliding surface, too.

- HardTec 19400,
- LubroTec 19985,
- DuroTec 19910.

I have carried out the following research-work with the powders chosen:

Performing spraying-application tests during which I examined the density (porosity), the hardness, the bond strength, the conditions of surface energy, the adsorption – and emission capacity of lubricant of surface layers by applying several spraying distances which is the most subjective technological parameter in case of manual technology.

The main variable of my tests are:

- generally suggested, producers' spraying distance (180 mm),
- increased with 40% the spraying distance in extreme value,
- reduced with 40% the spraying distance in extreme value, and
- using further spraying distances between extreme values.

I have evaluated the layers sprayed on the basis of structural, mechanical, surface energy and of lubricant oil adsorption – and emission characteristics. Based on processing the measuring results got I have established trends and connections between the characteristics of layers and spraying distances. I revealed the connections between the similarity of certain powder compositions and technological characteristics. I made more exact the technological knowledge connected to certain powders for representing in the service data base. The results of the research-work simplifying widen the data base of technological planning resulting more successful selection of powder compositions, supporting the complex technological operation of the shafts thermally sprayed from the service planning to the rejection and presently don't represent or represent only in limited degree attainable information on the professional field.

## 7. PUBLICATIONS IN CONNECTION WITH THE THEME OF DOCTORAL DISSERTATION

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3. Fazekas L., Tiba Zs., (2009): Testing the sprayed layers applied on machine element. Technological Engineering 2009/2., Slovak Republic, Zilina. pp. 23-26.
4. Fazekas L., Tiba Zs. (2010).: Interlaminar strength-tests of the surface layer built up with cold metal spraying methods during renewals, Machine Design 2010, Serbia, Novi Sad. pp 309-312.
5. Fazekas L., Tiba Zs., Kalácska G. (2011): The examination of the lubricant storing and releasing ability of thermally sprayed surfaces. Technological Engineering, Slovak Republic, Zilina. (in print)
6. G. Kalácska, L. Fazekas, R. Keresztes, A. Tóth, J. Szépvölgyi (2011): Cold flame-sprayed and oil-impregnated porous metallic coatings. Applied Surface Science. Elsevier. (in print)

### Articles in Hungarian language:

7. Fazekas L., Márton T. (1996): Fém-szórás alkalmazási lehetőségének gyakorlati megoldása a Hajdú Volán Rt-nél. = Gépgyártástechnológia. XXXVI. No.5. 7-9 o.
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12. Fazekas L., Pálincás I. (2009): Karbantartás-, tribológia és az alkatrészfelújítás kapcsolata. GÉP LX. Évfolyam, 4-5., 62-66. o.