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# CHARACTERIZATION OF PERFORMANCE COATINGS USING THE MULTI-CRITERIA ANALYSIS METHOD

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***Abstract:*** *The paper presents a method for evaluating surface properties of various materials and coatings, based on multi-criteria analysis. Newly developed materials, have a complex surface topology due to the manufacturing processes enabling strict surface parameter control.*
*Evaluating these materials is a costs and time consuming process. The main objective of the presented method is to offer a good characterization of the surface properties, based on basic laboratory measurements and to enable an effective comparison tool between two or more materials with similar properties.*
*The method was developed by analyzing the basic surface parameters of three performance coatings. The measured surface values were transposed into specific parameters of the multi-criteria analysis method and a final comparison was done in order to determine the best material. In order to confirm the method, more complex investigations (endurance tests on a specific test rig and scanning electron-microscope investigations) were done in parallel. The results of these investigations confirmed the results obtained by using the multi-criteria analysis method.*
***Keywords:*** *performance materials, coatings, surface, multi-criteria analysis, tribology*

## 1. INTRODUCTION

For evaluating a series of performance coatings with different surface profile parameters, a method was developed, enabling an effective characterization of the coatings by using only basic laboratory measurements. The method is based on the multi-criteria analysis principle and basically enables the fast evaluation of data collected from specific tests like roughness and friction measurements. By using this method, time consuming endurance tests and costly scanning electron-microscope investigations can be eliminated.

## 2. DESCRIBING THE PERFORMANCE COATINGS

Three types of performance coatings were analyzed. Their specific parameters are presented in Table 1. The coating is an alloy of chrome and has a granular surface shape, enabling the depositing of lubrication material [3]. As seen in Table 1, the main differences between the coatings, consists in their roughness profile and structure type. Coatings are considered having a closed structure, when a certain degree of overlapping exists between its spheres [5].

**Table 1:** Main characteristics of the performance layers

| | **Coating 1** | **Coating 2** | **Coating 3** |
|---|---|---|---|
| **Structure Type** | Open | Open | Closed |
| **Average Maximum Profile Height Rz [µm]** | 9,5 | 32,9 | 17,84 |
| **Density of Spheres [Sph./cm]** | 227 | 87 | 132 |
| **Hardness HV0,1** | 1000 | 1000 | 1000 |
| **Layer Thickness [µm]** | 20 | 70 | 70 |

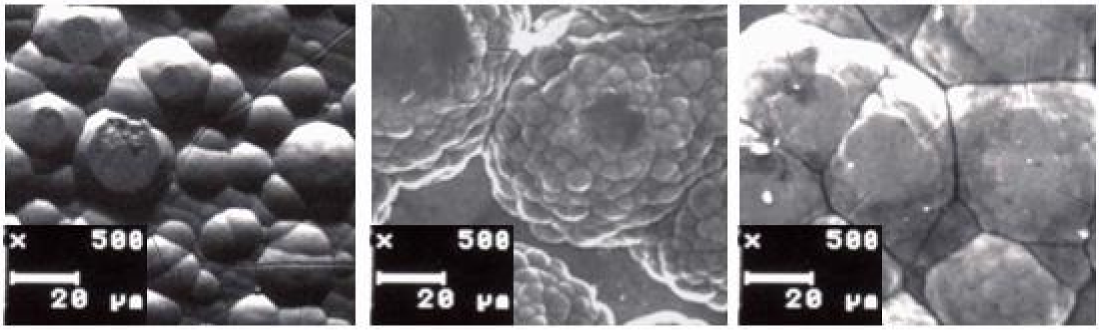

**Figure 1:** Surface view of the three performance coatings

## 3. DETERMINING THE MECHANICAL PROPERTIES OF THE COATINGS

Mechanical properties of the coatings were organized in four main categories:

- Bearing area (based on surface roughness)
- Friction (at rotary and oscillatory movement)
- Wear (linear and volumetric)

**Figure 2**: Determining the roughness profile

**Figure 3:** Determining friction and wear

The bearing area was determined by measuring the roughness profile of coatings using a basic roughness meter, as shown in Figure 2. Friction and wear were measured using a tribometer, pictured in Figure 3, capable of rotary and oscillatory movement [2,5]. Measurement results were only organized as data in specific folders. Their evaluation will be done by using a multi-criteria analysis method.

## 4. ON THE MULTI-CRITERIA ANALYSIS METHOD

In order to evaluate and rank the three coatings based on the experimental results, various models and methods of decision taking were analyzed. Considering the efficiency to complexity ratio, the "Electric" model developed by the General Electric Company and the multi-criteria analysis method were chosen [1].

These analysis techniques offer very accurate and objective results, for the following reasons [4]:

- the contribution of each criteria is established by comparing them to each other
- the relative position between two criteria can be of equality, superiority or inferiority
- marks are awarded separately for each criteria
- the comparative analysis of variant is done separately, considering each criteria

## 5. ESTABLISHING THE CRITERIA OF COMPARISON

The chosen criteria have to define essential properties and characteristics in order to individualize the variants to be analyzed. Starting from this concept, the chosen criteria and their abbreviations are shown in Table 2.

**Table 2:** The criteria chosen for the analysis

| Criterion | Symbol |
|---|---|
| 1 – Fabrication costs | **FC** |
| 2 – Bearing area | **BA** |
| 3 – Friction coefficient (rotary movement) | **FCR** |
| 4 - Friction coefficient (oscillatory movement) | **FCO** |
| 5 – Volumetric wear (rotary movement) | **VWR** |
| 6 - Volumetric wear (oscillatory movement) | **VWO** |
| 7 – Linear wear (rotary movement) | **LWR** |
| 8 - Linear wear (oscillatory movement) | **LWO** |
| 9 – Sensitivity at lubricant quality | **SLQ** |
| 10 – Sensitivity at movement type | **SMT** |

## 6. ESTABLISHING THE LEVEL OF EACH CRITERION

In order to establish a level of each criterion, a square table containing the ten criteria was generated, see Table 3. The contribution of the criteria was done by using the "Latin grid" with three values [1,6]. The criterion of one row is compared to the corresponding criterion of the column. If it is more important its value will be 1. If it is less important its value will be 0. If they are equally important the value will be 0,5.

**Table 3:** The table of levels

| | **FC** | **BA** | **FCR** | **FCO** | **VWR** | **VWO** | **LWR** | **LWO** | **SLQ** | **SMT** | Score *p* | Level | Contribution coefficient $\gamma_i$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FC** | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2,5 | **8** | 0,58 |
| **BA** | 1 | 0,5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3,5 | **7** | 0,9 |
| **FCR** | 1 | 1 | 0,5 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 4,5 | **6** | 1,3 |
| **FCO** | 1 | 1 | 1 | 0,5 | 0 | 0 | 0 | 0 | 1 | 1 | 5,5 | **5** | 1,77 |
| **VWR** | 1 | 1 | 1 | 1 | 0,5 | 0 | 1 | 1 | 1 | 1 | 8,5 | **2** | 4,16 |
| **VWO** | 1 | 1 | 1 | 1 | 1 | 0,5 | 1 | 1 | 1 | 1 | 9,5 | **1** | 5,6 |
| **LWR** | 1 | 1 | 1 | 1 | 0 | 0 | 0,5 | 0 | 1 | 1 | 6,5 | **4** | 2,37 |
| **LWO** | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0,5 | 1 | 1 | 7,5 | **3** | 3,14 |
| **SLQ** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,5 | 0 | 0,5 | **10** | 0,07 |
| **SMT** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0,5 | 1,5 | **9** | 0,3 |

By adding the values in the columns, the score "p", of each criterion is obtained (in Table 3, the antepenultimate column). The sum of all points is always equal to half the square of the criteria number: for the present case, for a number of 10 criteria, the sum of all points will be 50.
The score accumulated by each criterion, is used to determine its level and thus its rank (in Table 3, the penultimate column).

## 7. DETERMINING THE CONTRIBUTION COEFFICIENTS OF EACH CRITERION

For calculating the contribution coefficients $\gamma_i$, the Frisco method was used [1,6]. It is one of the most well known procedure used nowadays, and is given by the following equation:

$$\gamma_i = \frac{p + \Delta p + m + 0,5}{-\Delta p' + 0,5N} \qquad (1)$$

Where:
p – score of each criterion
Δp – difference between the actual criterion and the criterion corresponding to the lowest level
m – number of criteria surpassed by the actual criterion
Δp' – difference between the score of the actual criterion and the criterion corresponding to the highest level

N – number of criteria
The contribution coefficients of each criterion are shown in the last column of Table 3.

## 8. GRANTING OF MARKS TO EACH CRITERION

The procedure of granting marks to each criterion, gives the presented method a certain character of subjectivity. The German VDI 2225 standards, recommend only five marks [1,6]. For the present project, a notation with marks from 1 to 10 was considered. The granted notes are shown in Table 4. Except criterion FC (fabrication costs), the marks Ni, highlighted in Table 4, are actually averages of the marks granted to the respective criterion. For example, the VWO (volumetric wear at oscillatory movement) criterion was granted a mark for its behavior at mixed lubrication, as well as hydrodynamic lubrication.

**Table 4:** The table of marks

| Criterion | | Coating 1 | Coating 2 | Coating 3 |
|---|---|---|---|---|
| Level | Symbol | $N_i$ | $N_i$ | $N_i$ |
| 1 | **FC** | 8 | 7,5 | 10 |
| 2 | **BA** | 9,25 | 8,5 | 9,5 |
| 3 | **FCR** | 9 | 7 | 9,5 |
| 4 | **FCO** | 7,5 | 8 | 9,75 |
| 5 | **VWR** | 8 | 9 | 9,5 |
| 6 | **VWO** | 7,5 | 8,5 | 9,5 |
| 7 | **LWR** | 7 | 8 | 10 |
| 8 | **LWO** | 10 | 8 | 9 |
| 9 | **SLQ** | 8,75 | 8,25 | 9 |
| 10 | **SMT** | 9,5 | 9,5 | 8 |

## 9. DETERMINING THE RANKING OF VARIANTS

The final ranking (also called the raking of variants), is calculated tabular, using the matrix of consequences, shown in Table 5. In this table, the weighted score of each criterion is calculated. This is the product of the marks granted the criterion, amplified by the contribution of the respective criterion. By adding for each of the variants the weighted score, the final score is obtained.
According to the values shown in Table 5, it can be concluded that the final ranking of the analyzed coatings is: coating 3, coating 1 and coating 2 ; meaning that the coating with the best properties is coating 3 by achieving a score of 195,09.

**Table 5:** The table of scores

| | | Coating 1 | | Coating 2 | | Coating 3 | |
|---|---|---|---|---|---|---|---|
| Criterion | $\gamma_i$ | $N_i$ | $N_i\,\gamma_i$ | $N_i$ | $N_i\,\gamma_i$ | $N_i$ | $N_i\,\gamma_i$ |
| **FC** | 5,6 | 8 | 44,8 | 7,5 | 42 | 10 | 56 |
| **BA** | 4,16 | 9,25 | 38,48 | 8,5 | 35,36 | 9,5 | 39,52 |
| **FCR** | 3,14 | 9 | 28,26 | 7 | 21,98 | 9,5 | 29,83 |
| **FCO** | 2,37 | 7,5 | 17,77 | 8 | 18,96 | 9,75 | 23,1 |
| **VWR** | 1,77 | 8 | 14,16 | 9 | 15,93 | 9,5 | 16,81 |
| **VWO** | 1,3 | 7,5 | 9,75 | 8,5 | 11,05 | 9,5 | 12,35 |
| **LWR** | 0,9 | 7 | 6,3 | 8 | 7,2 | 10 | 9 |
| **LWO** | 0,58 | 10 | 5,8 | 8 | 4,64 | 9 | 5,22 |
| **SLQ** | 0,3 | 8,75 | 2,62 | 8,25 | 2,47 | 9 | 2,7 |
| **SMT** | 0,07 | 9,5 | 0,66 | 9,5 | 0,66 | 8 | 0,56 |
| Final score | | **-** | **168,6** | **-** | **160,25** | **-** | **195,09** |

## 10. CONCLUSION

A procedure, based on the multi-criteria analysis, for ranking performance coatings was developed. It enables a fast evaluation of laboratory measurements. Three different coatings were used for this application. After preliminary laboratory measurements, consisting in surface and tribological measurements, ten evaluation criteria were determined. By using a "latin grid" of three values, the level and the contribution coefficient of each criteria was calculated. By granting marks, the final ranking of the three coatings was established.


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