Abstract: - Metalized coatings do represent special solution for ensuring wear resistance, good lubrication or, high corrosion protection characteristics of parts submitted to severe “working” condition. Some of the materials used in metalizing are represented by special alloyed steels. Usually, the resulted coatings need further machining, by turning or grinding. So, their surface roughness do represent an important parameter to be known or, rather, estimated by the values of process parameters values. This paper presents applied statistics methods used for determining surface roughness models as function of turning process parameters, such as: cutting speed, feed and depth, cutting tool wear and nose radius. The metalized materials studied are, conventionally called “soft steels”, due to their micro-hardness values, about 300 ÷ 350 HV₀.₀₅.

Key-Words: - metalized coating, turning, process parameter, surface roughness, statistic model

1 General Aspects
Thermal spraying, or metalizing process, was developed by Max Ubrich Schoop, in Switzerland (1910). It can de defined as the process where pure or alloyed metal is melted in a flame and atomized, by a blast of compressed air into fine spray [2], [6].

Coating materials available for thermal spraying include metals, alloys, ceramics, plastics and composites. They are fed in powder or wire form, heated to a molten or semi-molten state and accelerated towards substrates in the form of micrometer-size particles. Combustion or electrical arc discharge is usually used as the source of energy for thermal spraying [8].

Depending on material type (wire, or powder) and energy source (combustion, electric arc, or plasma arc) there are many kinds of metalizing processes – see figure 1. Each of them can be characterized by benefits and disadvantages, as mentioned in available specific references.

Due to the high temperature and velocity of the metal drops, when impacting the surface they flatten and adhere forming a multilayer structure.- as shown in figure 2. As the molten metal is “sprayed” by a large amount of air, the part being metalized does not heat up too much.

Coating quality is usually assessed by measuring its porosity, oxide content, macro and micro-hardness, bond strength and surface roughness. Generally, the coating quality increases with increasing particle velocities [8].

![Fig. 1 Type of metalizing processes](image1.png)

![Fig. 2 Thermal sprayed coating structure](image2.png)
Commonly used for corrosion, or reconditioning worn parts, most of the times the metalized coatings do “require” machining, polishing or brushing. This is due to the fact that prescribed geometrical precision, as well as surface roughness of the metalized surfaces can not be obtained directly in the metalizing process.

Frequently used machining procedures are turning and grinding. So, a correct set of machining parameters values has to be known, so that optimum machinability and surface quality to be ensured.

The available specific references data, mentioned above, are poor quantitative ones and seldom refer to Romanian produced metalizing steels – that are really of great interest for Romanian industry.

Determining statistic models of surface roughness dependence on process parameters, in turning machined soft steels metalized coatings, has been considered fit [3].

The studied materials are Inox 18-8 and S12Mn2Si, Romanian made special steels, widely used in reconditioning worn parts.

2 Applied Statistic Method

It is considered [3], [4] that a process “developing” within a certain technological system, can be defined by the interdependence relation (1):

\[ Y = \Gamma(z_1, z_2, \ldots, z_n) \]

called process function, where:

- \( z_j \), \( j = 1, 2, \ldots, k \) represents the independent process variables (controllable inputs);
- \( Y \) – the dependent process variable (output);
- \( \Gamma \) - the type of dependence relationship.

The studied variables are presented next.

⇒ Independent variables (controllable inputs), \( z_j \):
  - cutting speed, \( v \) [m/min];
  - cutting feed, \( f \) [mm/rot];
  - cutting depth, \( a_f \) [mm];
  - cutting tool nose radius, \( r \) [mm];
  - cutting tool wear, \( V_B \) [mm];
  - Vickers micro-toughness, \( H_{V0.05} \)

⇒ Dependent variables (output), \( Y \)
  - surface roughness, \( R_a \) [\( \mu \)m].

⇒ The type of dependence relationship – are polynomial and exponential type ones.

The statistic models, in fact regression models, to be determined, require statistic experiments design - see table 1, where \( x_j \) is the coded variable.

<table>
<thead>
<tr>
<th>Run</th>
<th>( x_1 )</th>
<th>( x_2 )</th>
<th>( x_3 )</th>
<th>( x_4 )</th>
<th>( x_5 )</th>
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So, when there are four independent variables, the experiment design considered was conventionally called P 2.1, when there are five – the experiment design is P3, while when there are the most significant three independent variables, it is a central composite design, CCD.
The number of replicates, for each experience in P type experiments design (P 2.1 and P 3) equaled three, while in CCD design, it equaled five.

The software used in regression analysis are:
- REGS – for P 2.1 and P3 designs [11];
- DOE KISS -for CCD design [5].

3 Experiments and Results
Research involved Romanian made steels, for thermal spraying, Inox 18-8 and S12Mn2Si. Their chemical structure, as well as most important mechanical properties are presented in table 2.

The metalizing process was an electric arc one, with specific parameters values evidenced in table 3. A scheme of the process is to be noticed in figure 3.

Metallographic structure of the obtained coatings, sprayed on exterior cylindrical surface of OLC 45 (STAS 880-80) sample is shown in figure 4, while the image of a sample is presented by figure 5.

<table>
<thead>
<tr>
<th>Table 2</th>
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<tbody>
<tr>
<td><strong>Chemical structure and mechanical properties</strong></td>
</tr>
<tr>
<td><strong>Material</strong></td>
</tr>
<tr>
<td>Inox 18-8</td>
</tr>
<tr>
<td>S12Mn2Si</td>
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</tbody>
</table>

<table>
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<tr>
<th>Table 3</th>
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<tr>
<td><strong>Table 3</strong></td>
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<tr>
<td><strong>Electric arc metalizing process parameters</strong></td>
</tr>
<tr>
<td><strong>U [V]</strong></td>
</tr>
<tr>
<td>26</td>
</tr>
</tbody>
</table>

U – electric arc voltage; h – spraying distance; I - current intensity; p_a - pressure of compressed air

The experiments were done by considering, both, limited variation domains and certain well defined values of the independent variables studied, as shown in table 4.

Turning procedure fitted for the studied material, was exterior cylindrical semi-finishing turning and the cutting tool used was conventionally called K20 (based on its mechanic and geometric characteristics).
Table 4

<table>
<thead>
<tr>
<th>Independent variables values</th>
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<tbody>
<tr>
<td>v [m/min]</td>
<td></td>
<td>23</td>
<td>36</td>
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<tr>
<td>f [mm/rot]</td>
<td>0.20</td>
<td>0.25</td>
<td>0.315</td>
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<tr>
<td>a_a [mm]</td>
<td>0.35</td>
<td>0.375</td>
<td></td>
</tr>
<tr>
<td>VB [mm]</td>
<td>0.14</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>r [mm]</td>
<td>0.40</td>
<td>0.40</td>
<td></td>
</tr>
</tbody>
</table>

Table 5

<table>
<thead>
<tr>
<th>Experiments results</th>
<th>Surface roughness, R_a [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp. no.</td>
<td>1</td>
</tr>
<tr>
<td>Inox 18-8</td>
<td>2.60</td>
</tr>
<tr>
<td>Exp. no.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>3.82</td>
</tr>
<tr>
<td>S12Mn2Si</td>
<td>4.00</td>
</tr>
<tr>
<td>Exp. no.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>7.97</td>
</tr>
</tbody>
</table>

In order to determine statistic models required, first there were performed experiments considering four independent variables, meaning: v, f, a_a, and r. The experimental results are shown in table 5, while an image taken when measuring surface roughness can be noticed in figure 6.

Once determined the adequate regression model – see relations (2) and (3), there was studied the influence of the fifth independent variable.

⇒ for Inox 18-8

\[ R_a = e^{2.101 \cdot v^{0.127} \cdot f^{0.693} \cdot a_a^{0.097} \cdot (0.456)^r} \]  (2)

⇒ for S12Mn2Si

\[ R_a = e^{2.960 \cdot v^{0.313} \cdot f^{1.096} \cdot a_a^{0.307} \cdot (0.379)^r} \]  (3)

Some plotted graphs for the obtained statistic models are shown in figure 7.

Fig. 6 Image of surface roughness measuring

\[ f = 0.25 \text{ mm/rot} \]
\[ v = 36 \text{ m/min} \]
\[ a_a = 0.35 \text{ mm} \]

- surface roughness dependence on nose radius -
- relation (2) – for Inox 18-8

\[ v = 36 \text{ m/min} \]
\[ r = 0.8 \text{ mm} \]
\[ a_a = 0.35 \text{ mm} \]

- surface roughness dependence on cutting feed -
- relation (3) – for S12Mn2Si

Fig. 7 Graphical representations of surface roughness, R_a – statistic models with four independent variables
So, when considering the fifth independent variable, VB, the obtained statistic models are the ones presented by relations (4) and (5).

⇒ for Inox 18-8

\[ R_a = e^{2.349 \cdot v^{0.153} \cdot f^0.766 \cdot a_a^{0.136} \cdot (0.470) \cdot (3.360)^{VB}} \] (4)

⇒ for S12Mn2Si

\[ R_a = e^{3.023 \cdot v^{0.276} \cdot f^{1.054} \cdot a_a^{0.285} \cdot (0.391) \cdot (3.108)^{VB}} \] (5)

There should be mentioned that all of the above mentioned regression models have been determined by REGS program.

Some plotted graphs for the five independent variables statistic models are shown in figure 8.

Studying relations (4) and (5), one can notice that the three most important factors influencing surface roughness values are the next ones: cutting tool wear, VB; cutting feed, f; cutting tool nose radius, r.

![Graphical representation of surface roughness, Ra – statistic models with five independent variables](image)

That is why, a detailed study on their influence has been considered fit. It was done using CCD experiment design and, consequently, the DOE KISS software.

There were determined polynomial type models that enable pointing out the influence of each independent variable studied, as well as of their interactions, on dependent variable considered.

Due to license rights limitation (student version), there were considered only two variation levels (minimum, and maximum) for each of the independent variables (VB, f and r). The other independent variables v and aa values were considered to be medium (see table 4).

So, the obtained experimental results, are presented in table 6.

DOE KISS software regression analysis results are evidenced by the statistic models (6) and (7) – for coded variables and statistic models (8), (9) – for real variables.

⇒ for Inox 18-8

\[ R_a = 3.532 + 0.085 \cdot x_1 + 1.157 \cdot x_2 - 0.970 \cdot x_3 - 0.095 \cdot x_1 \cdot x_2 - 0.190 \cdot x_2 \cdot x_3 + 0.127 \cdot x_1 \cdot x_2 \cdot x_3 \] (6)

⇒ for S12Mn2Si

\[ R_a = 5.166 + 0.128 \cdot x_1 + 1.696 \cdot x_2 - 1.413 \cdot x_3 - 0.141 \cdot x_1 \cdot x_3 - 0.283 \cdot x_2 \cdot x_3 + 0.188 \cdot x_1 \cdot x_2 \cdot x_3 \] (7)

<table>
<thead>
<tr>
<th>Exp. no.</th>
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<tr>
<td>Inox 18-8</td>
<td>2.82</td>
<td>1.57</td>
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<tbody>
<tr>
<td>S12Mn2Si</td>
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<td>8.72</td>
<td>5.03</td>
<td>5.10</td>
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<tr>
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<td></td>
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</tr>
<tr>
<td></td>
<td>2.38</td>
<td>8.40</td>
<td>5.30</td>
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</tbody>
</table>

Table 6

Experiments results – for DOE KISS, CCD design

![Graphical representation of surface roughness, Ra – statistic models with five independent variables](image)
⇒ for Inox 18-8
\[
R_a = -3.07 + 11.81 \cdot VB + 32.82 \cdot f + 1.13 \cdot V_{cut} - 13.80 \cdot r - 10.20 \cdot V_{cut} \cdot f - 39.59 \cdot V_{cut} \cdot f \cdot r
\] (8)

⇒ for S12Mn2Si
\[
R_a = 0.48 + 17.52 \cdot VB + 48.38 \cdot f + 1.76 \cdot r - 64.44 \cdot V_{cut} \cdot f - 20.54 \cdot r \cdot f - 15.10 \cdot V_{cut} \cdot r + 58.62 \cdot V_{cut} \cdot f \cdot r
\] (9)

There should be mentioned some aspects like the following ones:
→ when using the software, the initial results do consider the coded values \(x_i\) for the independent variables studied
→ the relationship of real and coded variables values is given by (10):
\[
\begin{align*}
x_1 &= \frac{VB}{0.14} - 1; \\
x_2 &= 17.39 \cdot f - 4.48 \\
x_3 &= \frac{r}{0.40} - 2
\end{align*}
\] (10)

Some plotted graphs for the polynomial statistic models are shown in figure 9.

5 Conclusion
Metalized coatings do represent special solution for ensuring wear resistance, good lubrication or, high corrosion protection characteristics of parts submitted to severe “working” condition.

One frequently used machining procedures for metalized coatings is turning.

This study presents some statistic models of surface roughness dependence on process parameters, in turning machined soft steels metalized coatings, like Inox 18-8 and S12Mn2Si.

There were applied statistics methods, like experiment design and regression analysis, all aided by specific software, REGS and DOE KISS.

All the obtained statistic models have proven to be adequate and, thus, they should be used in determining estimated values of the output, when the values of inputs are known.

Further research development does involve other process parameters and / or metallised coating materials to be studied, as well as application of the obtained models in real time control of the process.

References: