THE RESEARCH REGARDING THE MECHANICAL TREATMENT THROUGH ROTOROLLING OF THE CYLINDRICAL SURFACES WITHOUT STEPS

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Abstract The objective of this paper is to apply a rotorolling process to metal exterior surfaces of revolution, of parts, through superficial cold plastic deformation (SCPD). To this purpose the authors start by the definition and schematic process using then a mathematical modeling, under the matrix form of the experimental data obtained in the following its practical application. The experimental research made, following the application process as a process of the rotorolling superficial cold plastic deformation, what allowed the establishment the influence of the factors and interactions take in to study between them. After the establishment experiments aimed to improve the quality of the processed surface trough decrease the roughness parameters (R_a).
Key words: rotorolling, superficialiy cold plastic deformation, hardening;

1. INTRODUCERE

The diversity of the constructive solutions that can be used in the devices construction for the superficial cold plastic deformation (SCPD) process application, through rolling or rotorolling; impose at one moment to take the most adequate decision in view of using any type of device to process the distinguished piece surfaces (Sava et al., 2009).

The main problem raised for the purpose and application of a combined process of rolling (through sliding – rolling, combined with the hitting through impact of the deforming tools, with the processing surface, the movements which to permit the realization of the hardening and finishing process, in the desired limits of surface layer) (Sava, 2010), consist in the design a complex constructive solutions.

The final solution proposed by the authors is started from the kinematic scheme of work head with three perpendicular rolles which may be followed in Fig. 1. and the final assembly of the entire device can be seen in Fig, 2 and Fig.3 (Sava, 2010).

This is endowed with 3 cylindrical rolls with frontal cam, mounted perpendicular to each other, which execute a rolling n_c motion towards the head principal axis.

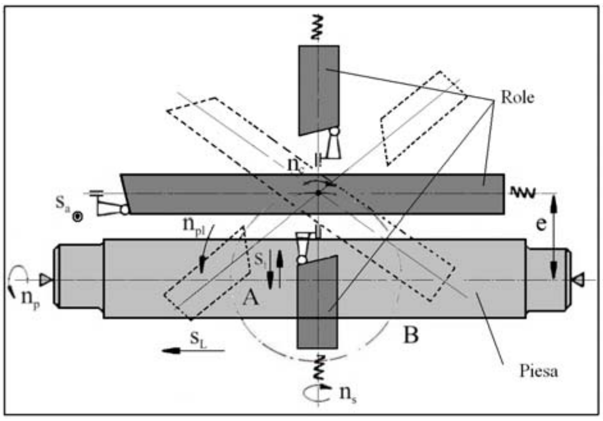

Fig.1. The kinematic schema of the rolling head with 3-pack perpendicular rolls

Besides the rotorolling movement the rolls also recive:

- a rotation motion n_c around their axis pursuant to the friction contact with the working piece, whose speed is n_p;
- a low ampliude alternatig rectilinium motion s_t, pursuant to the contact of a pusher with the frontal roll surface, having a rotating motion that also compress or relax an elastic element;
- a rotation of the entire head work with rolls $\mathbf{n_{p1}}$ (planetary) allaround the central device axis.

The entire assembly realise also the displaceament s_a to the piece, to obtain the rotorolling presure force, as well a longitudinal head feed s_l of the head work on the longitudina piece axis direction.

So, this final movment determine the metal slipping (flowings) fore the longitudinal direction of the front rolls on the piece (axial direction) the direct alternating straight-lined motion s_t, contributing in principal to his radial displacement and his planetary to his displacement on a conpound direction, resultant.(Lupescu, 1999)

The planetary motion determines also a second rollers pass when, the B point arrives in the initial position A

but, not of necessity, on the same piece surface elemantary unit. This objects depends by the rolling head longitudinal feed size and also, by the worked piece speed.
The drive to achieve these movements and how to do the pressing force can be seen in Fig. 2. (Sava, 2010)
An overview of its assambling to allow viewing of the realization mode for carrying out hydraulic pressure force is shown in Fig. 3. (Sava, 2010)
This device for rotorolling used for finishing and hardening cylindrical outside surface is characterized by the fact that, in order to ensure the quality of a cylindrical surface is used in a working head (6) which is manoeuvred by electric engine (2) through a belt (9), with the help of the gearbox (1). The p ressing force exerted by the work head on piece is given by the piston (10) manoeuvred by a hydraulic pump (12), using the lever (8).
The entire assembly is mounted on the holster machine - tools (5) and gearbox (1) and the head work (6) are guided on columns (3) through supports (4).

Fig.2. Rotorolling equipment

Fig.3. The entire rotorolling equipment

Following the design and materialisation device was realization some research regarding to the mathematical modeling, under the matrix form of the experimental data obtained in this practical application.
The performed experimental research allowed establishing a set of independent parameters influence at the surface quality thus analysed (Ra).

2. THE METHOD USED

For the exploitation of the experimental results obtained by measurements, we adopted for the establishing mathematical models of the influences parameters take in to account on the surface roughness, on the deviations from circularity and the microhardness in the surface layer, in matrix form with the method introduced by Vigier and Sisson, (Pillet, 1992).
It was noted here that the application of this variant by mathematical modeling assureing the following advantages:
- The models include interactions between factors and allow the estableshment of their effects;
- It is possible to realization a classifications, in terms of significance the effects of factors and interactions between them;
- The representation in graphic form of the average effects of factors, as well as the interactions between them is artless, and interpretation of models is available.
- Testing the significance of the model is relatively artless, this is one way been recommended a approach by the realization of the variantes analysis, (Pillet, 1992), with the help of the SNEDECOR test (using *Fisher criterion*).
The method of modeling to allowable, in each case under study, determines the coefficients of a model by the form:

$$Y = M + mat + v_p + v_{sl} + p_a + mat \cdot v_p + t_{mat} \cdot v_{sl} + mat \cdot p_a + v_p \cdot v_{sl} + v_p \cdot p_a + v_{sl} \cdot p_a \quad (1)$$

Where: E - system response,
M - The overall average.
The number of degrees of freedom for factors determined by the relationship:

$$ngl_i = niv_i - 1 \quad (2)$$

Where: $\boldsymbol{niv_i}$ - number of factor levels i,
and the number of freedom degrees for the interaction was determined by the relationship:

$$N_{i,j} = ngl_i \cdot ngl_j = (niv_i - 1) \cdot (niv_j - 1) \quad (3)$$

Number of freedom degrees the model was given by the sum of numbers of freedom degrees of factors and interactions, plus an overall average degree of freedom for M.

Taking into account the fact that each factor was considered at two levels, is result, for the mathematical model above:

4x (2-1) = 4 degrees of freedom for factors; 6x (2-1) x (2-1) = 6 degrees of freedom for interaction from where the resulting number of freedom degrees of the model considered:

$$N_{gl} = 1 + 4 \cdot (2-1) + 6 \cdot (2-1) \cdot (2-1) = 11 \quad (4)$$

By the same token, was result that minimum number of the mandatory tests experimental needed for solve the model, pursuant to *the rule of the number of freedom degrees*, (Pillet, 1992), it is 11. The number of 16 experimental tests realized in the 2^4 complete factorial experimental plans was enough decided.

How the complete factorial experimental plan is orthogonal, it result that the condition of orthogonality is accomplished, (Pillet, 1992), which takes into account the effect of an action to avoid damage calculation, either factor or interaction between factors, by the effect of another action.

The mathematical model that expresses the effects and interactions factors of these on the system's response was left from the general matrix form:

$$Y = M + \sum_{i=1}^{n} \left(\begin{bmatrix} Ef_{i,1} & Ef_{i,2} & .. & Ef_{i,k} \end{bmatrix} \cdot \begin{bmatrix} Af_i \end{bmatrix} \right) + \sum_{\substack{i,j=1 \\ i \neq j \\ i<j}}^{n} \left({}^{t}\begin{bmatrix} Af_i \end{bmatrix} \cdot \begin{bmatrix} If_{i,1}f_{j,1} & \cdots & If_{i,1}f_{j,k} \\ \cdots & \cdots & \cdots \\ If_{i,k}f_{j,1} & \cdots & If_{i,k}f_{j,k} \end{bmatrix} \cdot \begin{bmatrix} Af_j \end{bmatrix} \right) \quad (5)$$

where: Y - response system;

M - general media;

$Ef_{i,l}$ - the effect of environmental of factor i at the lever l;

$[Af_i]$ – the matrix of factor i with form:

$\begin{bmatrix} 1 \\ 0 \end{bmatrix}$ for the factor situated at the lever 1 and

$\begin{bmatrix} 0 \\ 1 \end{bmatrix}$ for the factor situated at the lever 2;

${}^{t}[Af_i]$ – the transposed of the factor matrix i;

k – the levels number of the considered factor;

n – number of the considered factors;

$If_{i,l}f_{j,h}$ – the interaction effect between the factor i at level l and factor j at level h.

Customize the model for equation (5) for the case of experimental plan realizaed, was conducted at obtaining the next matrix form:

$$\begin{aligned} Y = M &+ \begin{bmatrix} E_{mat1} & E_{mat2} \end{bmatrix} \cdot \begin{bmatrix} A_{mat} \end{bmatrix} + \begin{bmatrix} E_{v_p1} & E_{v_p2} \end{bmatrix} \cdot \begin{bmatrix} A_{v_p} \end{bmatrix} + \begin{bmatrix} E_{v_{sl}1} & E_{v_{sl}2} \end{bmatrix} \cdot \\ &\begin{bmatrix} A_{v_{sl}} \end{bmatrix} + \begin{bmatrix} E_{P_a1} & E_{P_a2} \end{bmatrix} \cdot \begin{bmatrix} A_{P_a} \end{bmatrix} + {}^{t}\begin{bmatrix} A_{mat} \end{bmatrix} \cdot \begin{bmatrix} I_{mat1,v_p1} & I_{mat1,v_p2} \\ I_{mat2,v_p1} & I_{mat2,v_p2} \end{bmatrix} \cdot \begin{bmatrix} A_{v_p} \end{bmatrix} + \\ &+ {}^{t}\begin{bmatrix} A_{mat} \end{bmatrix} \cdot \begin{bmatrix} I_{mat1,v_{sl}1} & I_{mat1,v_{sl}2} \\ I_{mat2,v_{sl}1} & I_{mat2,v_{sl}2} \end{bmatrix} \cdot \begin{bmatrix} A_{v_{sl}} \end{bmatrix} + {}^{t}\begin{bmatrix} A_{mat} \end{bmatrix} \cdot \begin{bmatrix} I_{mat1,P_a1} & I_{mat1,P_a2} \\ I_{mat2,P_a1} & I_{mat2,P_a2} \end{bmatrix} \cdot \\ &\begin{bmatrix} A_{P_a} \end{bmatrix} + {}^{t}\begin{bmatrix} A_{v_p} \end{bmatrix} \cdot \begin{bmatrix} I_{v_p1,v_{sl}1} & I_{v_p1,v_{sl}2} \\ I_{v_p2,v_{sl}1} & I_{v_p2,v_{sl}2} \end{bmatrix} \cdot \begin{bmatrix} A_{v_{sl}} \end{bmatrix} + {}^{t}\begin{bmatrix} A_{v_p} \end{bmatrix} \cdot \begin{bmatrix} I_{v_p1,P_a1} & I_{v_p1,P_a2} \\ I_{v_p2,P_a1} & I_{v_p2,p_a2} \end{bmatrix} \cdot \\ &\begin{bmatrix} A_{P_a} \end{bmatrix} + {}^{t}\begin{bmatrix} A_{v_{sl}} \end{bmatrix} \cdot \begin{bmatrix} I_{v_{sl}1,P_a1} & I_{v_{sl}1,P_a2} \\ I_{v_{sl}2,P_a1} & I_{v_{sl}2,P_a2} \end{bmatrix} \cdot \begin{bmatrix} A_{P_a} \end{bmatrix} \end{aligned} \quad (6)$$

To solve the above mathematical model, respectivily for the determination the matrix effects and interactions factors, were used for calculating the following relationships:

For average general:

$$M = \frac{1}{N_{ex}} \cdot \sum_{i=1}^{N_{ex}} Y_i \quad (7)$$

where: N_{ex} – the total number of experimental tests performed on the output parameter Y, $N_{ex} = 16$

Y_i – the experimental values of output parameter;

Y – (the response of the system studied) at the experimental test i.

For the average effects of factors, (Pillet, 1992)., defined as half the corresponding global effects:

$$Ef_{i,j} = \frac{\sum_{h=1}^{N_i} Y_{ij,h}}{N_i} - M \quad (8)$$

Where:

Ef_{ij} - the average effect of the factor i at level j;

N_i - number of tests from the experimental plan where the factor i it is at the level j;

$Y_{ij,h}$ – the system response, measured, at the test by the order h between factors i is located at level j;

For interactions:

$$If_{i,l}f_{j,k} = M_{il,jk} - M - Ef_{i,l} - Ef_{j,k} \quad (9)$$

Where:

$If_{i,l}f_{j,k}$ – the interaction between factor i at level l and factor j al level k;

$M_{il,jk}$ – the average responses Y when factor i it is at level l and the factor j it is at level k;

$Ef_{i,l}$ şi $Ef_{j,k}$ – the average effects of factor i at the level l and respectively the factor j to level k.

Once the effects of values factors calculated, with equation (8) and the interactions between factors, with equation (9), have a established if these effects are significant, that if they are actually associated with relevant factors, or if not than on system manifestation variability, due to the uncontrollable factors.

To test the significance of mathematical models obtained was applied the **Snedecor** test, which consisted in the comparison between the variance or interaction factor considered and the residual variance model, based on **Fisher** criterion.

The residual variance model is the variance how is not explained by factors controlled. It is therefore the deviations variance between the mathematical model and measured responses and was calculated with the equation:

$$V_R = \frac{\sum r^2}{N_{rez}} \tag{10}$$

where: r - residues, calculated as the difference between theoretical and measured response:

$$r = Y - Y\sim \tag{11}$$

N_{rez} – number of freedom degrees for the residues, calculated with the equation:

$$N_{rez} = N_{ex} - N_{gl} \tag{12}$$

Variance for factor *i* was calculated with the equation:

$$V_i = \frac{N_{ex}}{niv_i \cdot (niv_i - 1)} \cdot \sum (Ef_i)^2 \tag{13}$$

and variance for interaction between factors i and j was calculated with the equation:

$$V_{i,j} = \frac{N_{ex}}{niv_i \cdot (niv_i - 1) \cdot niv_j \cdot (niv_j - 1)} \cdot \sum (If_i f_j)^2 \tag{14}$$

Testing the significance for the factor *i* or interaction between factors *i* and *j* to consisted of comparing the calculated values of the **Fisher** criterion, given by the equation:

$$F_{\max} = \frac{V_i}{V_R} \tag{15}$$

respectively:

$$F_{\max} = \frac{V_{i,j}}{V_R} \tag{16}$$

with the table value of the criterion, F_T, adopted, for a 5% risk (therefore a 95% confidence coefficient) and for numbers of freedom degrees:

$$\nu_1 = ngl_i = niv_i - 1 \tag{17}$$

respectively:

$$\nu_1 = N_{i,j} = (niv_i - 1) \cdot (niv_j - 1) \tag{18}$$

and

$$\nu_2 = N_{rez} \tag{19}$$

which, for the models in our case, it meant:

$\nu_1 = 1$

$\nu_2 = 5$

resulting, from the corresponding table, value:

F_T (0, 95; 1; 5) = 6, 61.

For the data processing results of measurements and solving the mathematical models in matrix form, including the significance testing, for each case take in to study were elaborated, using Microsoft Excel, a series of worksheets for the spreadsheet.

Using this way by processing was permit to drawing and viewing the appropriate diagrams for the effects of factors highlight, as will be presented below.

3. RESULTS

After making a series of experiments were considered four input parameters, namely:

Mat – represent the material used

V_p – represent the play speed,

S_l – represent advance longitudinally

P_a - hydraulic pressure,

In table 1 are presented these input parameters how favour the highlighter variation roughness Ra depending on the circumstances.This parameter was obtained by measuring with the **Surtronic 3 +,** for all point from the experimental plane.

Table 1. The value parameter Ra

Factors → The number of tests	**Mat**	V_p	S_l	P_a	R_a
1	1	1	1	1	2.55
2	1	1	1	2	0.783
3	1	1	2	1	1.71
4	1	1	2	2	0.622
5	1	2	1	1	1.6
6	1	2	1	2	0.912
7	1	2	2	1	1.09
8	1	2	2	2	0.402
9	2	1	1	1	1.29
10	2	1	1	2	0.646
11	2	1	2	1	1.14
12	2	1	2	2	0.469
13	2	2	1	1	0.654
14	2	2	1	2	0.615
15	2	2	2	1	0.784
16	2	2	2	2	0.397

In Figure 4 is presented graphically the value parameter Ra in the 16 points of the experimental plane. By processing the data from the table 1, after the algorithm presented above has been obtained for the mathematical model, how describes the influence of independent study factor and the interactions between them on the roughness, form illustrated in the relationship 4.

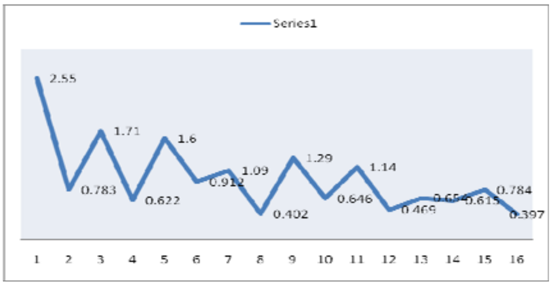

Fig. 4. The values of parameter Ra in the experimental plane points

$$R_a = 0.979 + [0.229625 \quad -0.229625]\cdot[A_{mat}] + [0.17225 \quad -0.17225]\cdot[A_{v_p}] + [0.15225 \quad -0.15225]\cdot[A_{v_{sl}}] +$$
$$+ [0.37325 \quad -0.37325]\cdot[A_{P_a}] + {}^t[A_{mat}]\cdot\begin{bmatrix} 0.035375 & -0.035375 \\ -0.035375 & 0.035375 \end{bmatrix}\cdot[A_{v_p}] +$$
$$+ {}^t[A_{mat}]\cdot\begin{bmatrix} 0.100375 & 0.100375 \\ 0.100375 & 0.100375 \end{bmatrix}\cdot[A_{v_{sl}}] + {}^t[A_{mat}]\cdot\begin{bmatrix} 0.155625 & -0.155625 \\ -0.155625 & 0.155625 \end{bmatrix}\cdot[A_{P_a}] +$$
$$+ {}^t[A_{v_p}]\cdot\begin{bmatrix} 0.01375 & -0.01375 \\ -0.01375 & 0.01375 \end{bmatrix}\cdot[A_{v_{sl}}] + {}^t[A_{v_p}]\cdot\begin{bmatrix} 0.148 & -0.148 \\ -0.148 & 0.148 \end{bmatrix}\cdot[A_{P_a}] +$$
$$+ {}^t[A_{v_{sl}}]\cdot\begin{bmatrix} 0.019 & -0.019 \\ -0.019 & 0.019 \end{bmatrix}\cdot[A_{P_a}] \qquad (20)$$

The result obtained by applying analysis of variance, after the shown above methodology for the presented model is shown in table 2.

Table 2 The analysis of variance for model parameter Ra

Factor	nivi*(nivi-1)	sum(Ef^2)	Variance factor	Fmax	Ft	significance
Mat	2	0.105455281	0.84364225	25.4325		S
Vp	2	0.059340125	0.474721	14.311		S
Sl	2	0.046360125	0.370881	11.1806		S
Pa	2	0.278631125	2.229049	67.1971		S
mat-vp	4	0.005005562	0.02002225	0.60359		N
mat-sl	4	0.040300563	0.16120225	4.85962	6.61	N
mat-pa	4	0.096876562	0.38750625	11.6818		S
vp-sl	4	0.00075625	0.003025	0.09119		N
vp-pa	4	0.087616	0.350464	10.5651		S
sl-pa	4	0.001444	0.005776	0.17412		N
Residual variance V_R				0.0331718		

It was realized a presentation in graphical form of the effects factors on the parameter Ra, after the modality recommended in the literature (Pillet, 1992), as in Fig. 5 (a, b, c, d).

A significant modality in point of graphic presentation, so the effects of factors and interactions, how making possible the comparison and ranking of these effects, is shown in Fig. 6

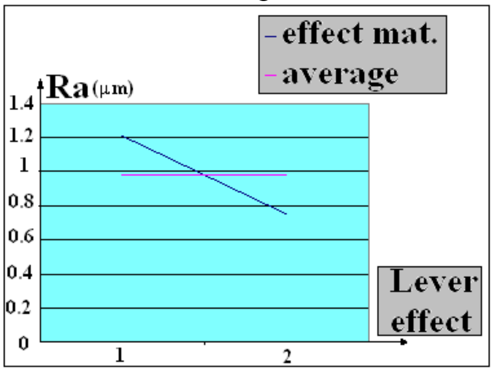

Fig.5a. The effect of independent factor (material) on the parameter Ra

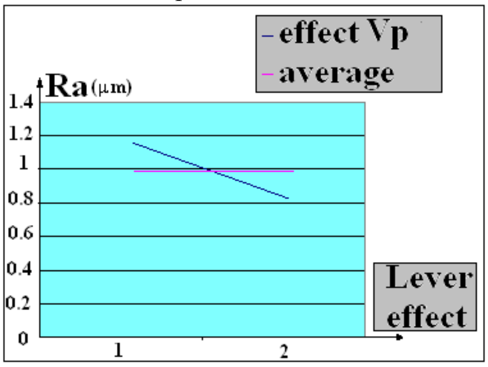

Fig.5b. The effect of independent factor (V_p – piece speed) on the parameter Ra

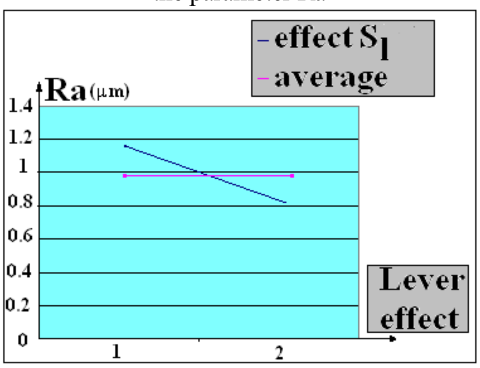

Fig.5c. The effect of independent factor (S_l – longitudinal advance) on the parameter Ra

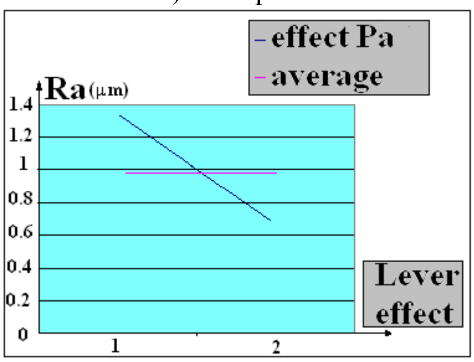

Fig.5d. The effect of independent factor (P_a – pressure) on the parameter Ra

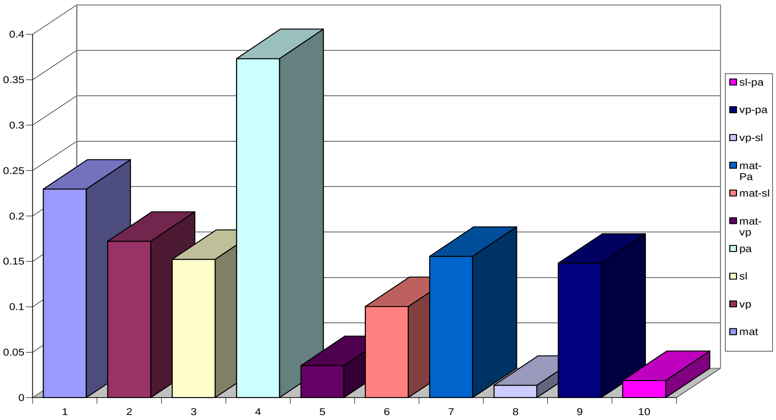

Fig. 6 The effects of factors and interactions on the parameter Ra

It is observed that in Fig. 6. in the further analysis of the effects of the factors an significant influence has pressure followed by the material used, and the interaction between factors on the parameter Ra show that Mat – P_a (material - pressure) is a significant effect to V_p – S_l (speed piece - advanced longitudinal) whose effect is insignificant.

4. CONCLUSIONS

In the analysis performed could formulate the following conclusions:

- the values obtained for the parameter Ra of the cylindrical exterior surface roughness, measured on these surface, were situated in the concrete conditions of the partial research work between 0.4 ÷ 2.2 μm, these values are comparable with surface roughness values possible be obtained through the rolling operation;
- For the two steels under investigation, review all relevant factors have significant effects on the parameter Ra:

The effect is strongest for the two materials that of the P_a – factor (pressure). Increasing the value of this parameter leads to an importance reduction of the value surface roughness Ra parameter;

The effects of the other factors considered are slightly lower than the effects of kinematics parameters of the process, but are not neglected;

The weakest effect it has, for recalled model, the forward longitudinal S_l, which recorded a value numerically lower than the other three parameters analyzed.

5. FUTURE RESEARCH

Regarding future research will take place in point of use the rotorolling process; can also perform a series of experiments that may allow establishing the influence of the independent factors set on microhardness and hardening the surface layer thickness (HRV).

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