USING THE RANK CORRELATION METHOD FOR ORDERING THE FACTORS INFLUENCING THE RESULTS OF SOME WEAR TESTS

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Abstract: *There are situations in industrial practice and scientific research when the problem of selecting an alternative among several available alternatives arises. One of the methods that can be used in this sense is the rank correlation method. The application of the method involves going through some stages in which the results deriving from the opinions expressed by experts, i.e., people with professional and scientific knowledge in the problem addressed, are processed statistically. The paper presents the results of applying the rank correlation method for ordering the factors capable of exerting influence on the intensity of some wear processes. It was found that, according to the obtained results, the strongest influence will be exerted by the structure and hardness of the test sample material, followed by the chemical composition of the test sample material.*

Keywords: *wear test, influencing factors, ordering, rank correlation method*

1. Introduction

As a result of use, a tool is affected by a process of wear, thus losing the ability to use it. In the case of cutting tools, wear can be manifested by the appearance of a facet on the flank surface (as a result of the contact of this surface with the machined surface of the workpiece), a channel on the rake surface (due to the abrasive action of the chip), plastic deformation of the tool tip. It should be noted that wear processes also affect the integrity of other categories of parts, apart from cutting tools, especially when these parts are included in movable joints.

There are methods for assessing the amount and evolution of wear adapted to the different wear categories. Such methods may consider tracking the evolution of wear under normal conditions of use of tools or parts, but resorting to processes capable of accelerating the evolution of wear and obtaining useful wear information in shorter intervals.

Most methods are based on quantitative evaluations of material removal from the tested part, using dimensional damage or mass loss.

The main groups of factors that affect the wear values recorded by the tools are the following:

a) Chemical composition, structure, and some physical-mechanical properties of the tool material;

b) Chemical composition, structure, and some physical-mechanical properties of the material of the workpiece on which the tool acts;

c) Type of method used for wear testing;

d) The conditions for carrying out the wear test (the force exerted on the tool, the type and relative speed of the relative movement between the tool and the workpiece material in which the tool is tested, the roughness of the surface of the tool that comes into contact with the material used for testing, etc.).

It can be seen that a relatively large number of factors are capable of influencing the results of some wear tests.

For reasons of establishing an acceptable duration of the wear tests, it may sometimes be necessary to order the factors that can influence the wear processes so that, within the experimental wear tests, only the most important factors are taken into account or factors with a critical influence on the wear process.

On the other hand, until now, different methods have been applied to choose a solution to solve a problem, among several alternatives that could be used.

Research in this area has shown that there are methods of optimal selection of an alternative when several alternatives are available.

One of these methods of optimal selection of an alternative is *the rank correlation method* [Litchfield, 1955; Sternstein, 1962; Nichici, 1996].

The method has been applied in different variants to solve many problems. A more detailed description of the method and how the method can be applied is presented in [Nichici, 1996].

It can also mention the use of the method for the study of the factors capable of affecting the manufacturing process of electronic subassemblies [Crețu, 2013], for revealing the factors that influence the consumption of beer [Olteanu, 2013], for the evaluation and selection of the quality indices of the products [Stogul, 2011], for ordering the factors that affect the surface roughness during chemical processing [Botezatu, 2020].

In the present work, the results of some research related to using the rank correlation method for ordering previously established factors that could influence the wear of some test samples made of certain materials have been included.

2. Features of using the rank correlation

It is known that, in some cases, it is necessary to experimentally investigate how different input factors in a process influence the values of output parameters from that process. It is obvious that due to time conditions and the existence of a certain material base, experimental tests that consider the existence of many influencing factors cannot be carried out. In such situations, it is necessary to use a method that allows a justified selection of a limited number of factors whose magnitudes will be changed during the experimental research. As mentioned, one of these methods is the rank correlation method [Nichici, 1996; Slătineanu, 2020].

The method's name is in connection with the fact that the rank number of an entity in a set of entities has been assigned the rank name. The main steps to be followed when applying the rank correlation method are the following:

1. Identification of factors likely to exert influence on the values of a parameter of interest from a certain point of view;

2. Establishing the content of a form in which the opinions of specialists who have professional knowledge in the field of the investigated process will be recorded; these specialists will be assigned the title of *experts*, Based on his professional knowledge, each expert will have to propose a certain order of the influencing factors considered;

3. Inclusion of information from the form filled in by experts regarding the order of importance of the input factors in the so-called primary table;

4. Processing the information from the primary table, first of all by adding up the rank numbers proposed by the experts in the last line of the primary table. In this way, a first image of the possible order of input factors in the investigated process is obtained;

5. Possible correction of the ranks when it is found that one or more experts have given the same rank to several influencing factors. The correction is carried out with the help of a ratio between the sum of the ordinal numbers of the factors with the same rank given by the experts and the number of factors with the same rank. The new ranks of the input factors are included in a table that will be called the secondary table;

6. Checking the correlation that exists between the information in the primary table

and those in the secondary table; the check is performed using a correlation coefficient;

7. Checking the level of concordance of the ranks given by the experts, using a so-called consensus coefficient for which values between certain limits are accepted;

8. Elaboration of a graphic representation regarding the degree of significance of the input factors considered.

3. Ordering of influencing factors in the case of some wear tests using the rank correlation method

It is considered necessary to carry out some experimental tests intended to highlight the influence exerted by some factors on the mass or dimensional wear value of a test sample made of a certain material and using one or more manufacturing methods.

The documentary information led to the conclusion that there is a varied range of wear test methods, a first differentiation between them being made based on the test scheme used. In principle, the test sample of the test material is pressed with a known force on the surface of a counterpiece made of wear-resistant material. There is a relative movement with certain characteristics between the two elements directly involved in the wear process. In the analyzed case, it will be assumed, for example, that it is possible to carry out a wear test that involves pressing with a force *F* of known value a cylindrical or parallelepiped test sample on the surface of a counterpiece that performs a rotational movement (this is the method called conventional “pin-on-disk”, Fig. 1) [Hrițuc, 2021] or an oscillatory movement along a rectilinear direction.

In the aforementioned conditions, based on a preliminary analysis, it was assessed that the main factors able to exert influence on the mass or dimensional wear of the test sample are the following:

1. Chemical composition of the sample material;
2. The structure and hardness of the sample material;
3. Resistance to wear of the material of the counterpart;
4. Duration of the wear test;
5. The pressure force of the test sample on the surface of the counterpart;

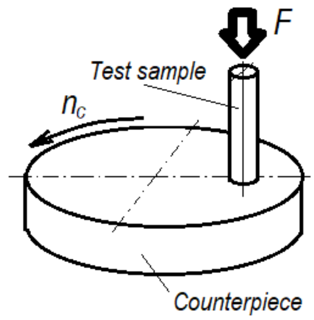

Figure 1: *Schematic representation of a wear test using a test sample pressed with a force F on a counterpiece that rotates at a rotation speed v_c.*

6. The type of relative movement between the test sample and the counterpiece;
7. The speed of the relative movement between the test sample and the counterweight;
8. Surface roughness of the test sample.

In the second stage of applying the rank correlation method, experts were consulted regarding the possible ordering of the influencing factors if the intensity of the influence exerted by each factor on an output parameter is taken into account, which, in the present case, is the mass or dimensional wear of the test sample made of a certain material.

In the third stage, Table 1 was completed, considered as the primary table. In the first line of the table, the factors assumed to have an influence on the value of mass or dimensional wear of the sample were written, and in the first column, the serial numbers of the experts consulted (in the present case, they being the authors of this paper and, respectively, other colleagues who knew the investigated process). In the places in the table, the ordinal numbers given by the experts to each of the considered influence factors were entered. The last line in the table contains the sum A_j of the ordinal numbers given by the experts for each of the influence factors considered; this means going through the fourth stage of the method.

A first analysis of the information in the primary table highlights that two consulted experts (experts 2 and 8) assigned the same rank to some of the input factors. This means that it is necessary to perform the necessary calculations to correct the ranks. To change the ranks, a corrected rank will be calculated as a ratio between the sum of the ordinal numbers corresponding to the places occupied by the

Table 1: Initial information on experts' ranking of factors capable of influencing wear test results

Expert no . (j)	Influencing factors, x_k							
	x_1 (chemical composition of the sample material)	x_2 (structure and hardness of the test sample material)	x_3 (the wear resistance of the counterpiece material)	x_4 (the duration of the test)	x_5 (the pressing force of the test sample on the counter piece)	x_6 (the type of the relative movement between the test sample and the counterpiece)	x_7 (the relative speed of movement between the test sample and the counterpiece)	x_8 (the roughness of the test sample surface)
1	1	2	5	4	7	6	8	3
2	1	1	6	2	3	4	4	5
3	1	2	5	3	4	7	6	8
4	3	1	2	7	5	4	8	6
5	1	3	6	2	7	5	4	8
6	1	3	4	2	5	7	6	8
7	1	2	5	3	4	6	7	8
8	2	1	4	2	2	3	3	5
9	3	2	7	1	4	5	6	8
10	2	1	7	3	5	4	6	8
A_j	16	18	51	29	46	51	58	67
$Q_i(1)$	1	2	5	3	4	5	6	7

factors given the same rank and the number of factors with the same rank.

The following values of the corrected ranks are thus reached: r_{21}=(1+2)/2=1.5, r_{24}=(5+6)/2=5.5, r_{82}=(1+3+4)/2=2.6. r_{83}=(5+6)/2=5.5.

The new situation will be reflected by the content of the secondary table (Table 2), with corrected data.

Since it was necessary to develop the secondary table, within the sixth stage, it is necessary to calculate a correlation coefficient between the information in the primary and the secondary table. In this case, the equation will be used:

$$r_s = 1 - \frac{6}{k^3 - k}\sum_{j=1}^{k}\left[Q_j(1) - Q_j(2)\right]^2 \quad (1)$$

Taking into account the available information, it follows:

$$r_s=1-[6/(8^3-8)]\cdot[(1-1)^2+(2-2)^2+(5-5)^2+(3-3)^2+(4-4)^2+(5-6)^2+(6-7)^2+(7-8)^2]^2=0.893 \quad (2)$$

Finding that the correlation coefficient r_s is close to the unit value, it is appreciated that there is an acceptable correlation between the information in Tables 1 and 2.

In the seventh stage, for the calculation of

Table 2: Corrected values of information regarding experts' ranking of factors capable of influencing wear test results

Expert no . (j)	Influencing factors, x_k							
	x_1 (chemical composition of the sample material)	x_2 (structure and hardness of the test sample material)	x_3 (the wear resistance of the counterpiece material)	x_4 (the duration of the test)	x_5 (the pressing force of the test sample on the counter piece)	x_6 (the type of the relative movement between the test sample and the counterpiece)	x_7 (the relative speed of movement between the test sample and the counterpiece)	x_8 (the roughness of the test sample surface)
1	1	2	5	4	7	6	8	3
2	1.5	1.5	6	2	3	6.5	6.5	5
3	1	2	5	3	4	7	6	8
4	3	1	2	7	5	4	8	6
5	1	3	6	2	7	5	4	8
6	1	3	4	2	5	7	6	8
7	1	2	5	3	4	6	7	8
8	2.6	1	4	2.6	2.6	5.5	5.5	5
9	3	2	7	1	4	5	6	8
10	2	1	7	3	5	4	6	8
A_j	17.1	18.5	51	29.6	46.6	55	62	67
$Q_i(1)$	1	2	5	3	4	6	7	8

the size of *the consensus coefficient* w, the relationship will be used:

$$w = \frac{12\sum_{j=1}^{k} \Delta_j^{\,2}}{m^2(k^3 - k) - m\sum_{i=1}^{m} T_i}, \qquad (3)$$

where Δj and T_i correspond to the equations:

$$\Delta_j = \sum_{i=1}^{m} a_{ij} - \frac{1}{k}\sum_{j=1}^{k}\sum_{i=1}^{m} a_{ij}, \qquad (4)$$

$$T_i = \sum_{j=1}^{k}(t_j^{\,3} - t_j), \qquad (5)$$

In the previous equations, i takes values from 1 to 10, and t_j corresponds to the number of identical ranks given by expert j.

The T_i values are determined first. It is found that the only non-zero values are T_2 and T_8, for which one obtains:

$$T_2=(2^3-2)+(2^3-2)=12 \qquad (6)$$

$$T_8=(2^3-2)+(3^3-3)=30 \qquad (7)$$

Thus, the sum of the T_i values is equal to 42. Next, the Δj^2 values are determined from the relationship (4). For Δ_1^2, one obtains, for example:

$$\Delta_1^2=[17,1-1/8\cdot 346.8]^2=689.0 \qquad (8)$$

The sum of the Δ_j^2 values is equal to 2607.3. With all the values of Δj^2, it becomes possible to calculate the consensus coefficient using the Eq. (3). It can be written like this:

$$w=(12\cdot 2607.3)/[10^2\cdot(8^3-8)-10\cdot 42]=0.626 \qquad (9)$$

Since the number of k factors (namely 8) considered is greater than 7, according to the recommendations in [Nichici, 1996], it is necessary to use the χ^2 criterion. In this sense, the relationship will be used:

$$\chi_{calc}^2=m(k-1)w \qquad (10)$$

Substituting the known values, it arrives at:

$$\chi_{calc}^2=10\cdot(8-1)\cdot 2607.3=182.511 \qquad (11)$$

It is necessary to compare the calculated χ_{calc}^2 value with a tabulated value of χ_{tab}^2, to determine whether there is an acceptable consensus between the opinions expressed by the experts. Considering a probability of 95% and a degree of freedom $v=k-1=7$, it is found that a tabulated value $\chi_{tab}^2=14.07$ is reached, which means a value lower than the calculated value χ_{calc}^2 (182,511>14.07), which means that there is a significant correlation between experts' opinions.

To develop a histogram-type graphic representation, one resort to calculating a degree of significance I_j for each of the factors considered, using, for example, a relationship of the form:

$$I_j=K/A_j \qquad (12)$$

Assuming a value of K=200 and considering the values of A_j in Table 2, all values for the degree of significance are determined.

With the help of these values, the histogram in Fig. 2 was developed.

According to the information determined by using the rank correlation method, it is found that the order of importance of the factors capable of exerting influence on the intensity of the wear process is as follows:

1) Chemical composition of the sample material;

2) Structure and hardness of the sample material;

3) Duration of the test;

4) The pressure force of the test sample on the counterpiece;

5) Resistance to wear of the material of the counterpart;

6) The type of relative movement between the test sample and the counterpiece;

7) The speed of relative movements between the test sample and the counterpiece;

8) Surface roughness of the test sample.

4. Conclusions

There are situations in which, before conducting experimental tests, it is necessary

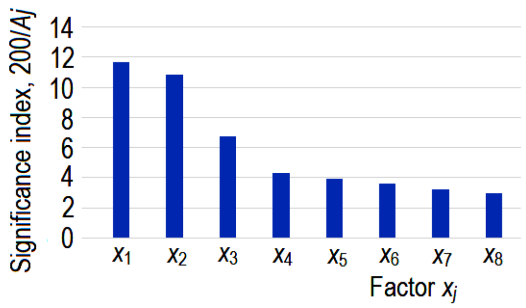

Figure 2: *Histogram that takes into account the significance index values.*

to establish the factors that could exert influence on one or more quantities of interest. In such situations, but especially when the number of factors of interest is large, the question arises of ordering these factors, by taking into account certain selection criteria. The problem can be solved by resorting to a method of selecting the most convenient alternative when several such alternatives are available. One of the methods that can be used is the rank correlation method. In this paper, the rank correlation method was used to order the factors that influence the intensity of a wear process in the case of a specific test. The method is based on statistical processing of the answers reached by consulting some experts who have scientific and professional knowledge in the field of the problem addressed. As a result of going through the stages corresponding to the application of the rank correlation method, it was found that the first most important factors capable of affecting the results of some wear tests are the chemical composition of the test sample material, the structure and hardness of the test sample material and, respectively, the duration of the test. In the future, it is intended to develop some experimental wear tests for steel test samples manufactured by certain processes. Another objective that could be addressed could consider comparing the results obtained by using several methods of selecting an alternative to solve a problem when several such alternatives are available.

References

1. [Botezatu, 2020] Botezatu, C.V., Oroian, B., Condrea, I., Boca, M.A., Hriţuc, A., Ciobanu, D. G., Slătineanu, L., *Use of rank correlation method for ordering factors capable of affecting surface roughness in chemical machining*, Buletinul Institutului Politehnic din Iaşi, 66 (70), 2, 2020.

2. [Condrea, 2021] Condrea, I., Hrițuc, A., Oroian, B., Boca, M., Botezatu, C., Slătineanu, L., *Ordering the influence factors of the flat milling process*, Conference of the Technical University of Iași Doctoral School, 2021.

3. [Crețu, 2013] Crețu, L.-A., *Studiul factorilor care influențează procesul de fabricare a subansamblelor electronice prin metoda corelație de rang*, Buletinul AGIR, Supliment, 1, 2013, 61-64.

4. [Hrițuc, 2020] Hrițuc, A., Slătineanu, L., Boca, M.A., Sover, A., Nagîț, G., Dodun, O., Coteață, M., Mihalache, A., *Abrasive erosion behavior of some plastic parts obtained by 3D printing*, Macromolecular Symposia, 396, 1, 2021, 2000288https://doi.org/10.1002/masy. 202000288

5. [Litchfield, 1955] Litchfield, J.T.Jr., Wilcoxon, F., *Rank correlation method*, Analytical Chemistry, 1955, 27, 2, 299–300, https://doi.org/10.1021/ac60098a03

6. [Lvovschi, 2014] Lvovschi, N. *Studiul matematico-statistic a industriei Moldovei în profil territorial*, Buletinul Institutului de Cercetări Ştiinţifice în Construcţii, N.5-CN, 2014.

7. [Nichici, 1996] Nichici, A., Cicală, E., Mee, R., *Prelucrarea datelor experimentale. Curs şi aplicaţii*, Universitatea „Politehnica”, Centrul de multiplicare, Timişoara, 1996.

8. [Olteanu, 2013] Olteanu, G.-A., *Studiul factorilor care influenţează consumul de bere prin metoda corelaţiei de rang*, Buletinul AGIR, Supliment, 1, 38-41, 2013.

9. [Slătineanu, 2020] Slătineanu, L. *Bazele cercetării științifice*, Editura PIM, Iași, 2020.

10. [Sternstein, 1962] Sternstein, L., *Note on the rank correlation method*, The Professional Geographer, vol. 14, no. 2, 1962

11. [Stogul, 2011] Stogul, L., Cîrja, J., Dabija, A., *Criterii de evaluare şi selectare a indicilor de calitate pentru produse din tricot*, 2011 available from http://repository.utm.md/bitstream/handle/5014/4082/Conf_UTM_2010_III_pg_146-147.pdf?sequence=1&isAllowed=y.

12. [Studiul, 2014] *Studiul centralelor eoliene in vederea imbunatatirii lor*, 2014, available from https://www.qdidactic.com/bani-cariera/constructii/electrica/studiul-centralelor-eoliene-in-vederea-imbunatatirii376.php.