SELECTING EQUIPMENT SOLUTION FOR THE CHARACTERIZATION OF THE FRICTION DRILLING PROCESS

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ABSTRACT: A process currently under researchers' attention in terms of making holes is the so-called friction drilling. The process is based on pressing a conical-shaped tool, driven in rotation, into the workpiece to be drilled. The analysis of the process highlights that there will be a variation of the axial force to the physical-mechanical properties of the workpiece material. To highlight the axial force variation, it was necessary to select, among several alternatives, a device that would make this possible. In this sense, the method of analytic hierarchy process was used. It was possible, thus, a justified selection of the device intended to allow obtaining additional information on the friction drilling process
KEYWORDS: friction drilling, axial force, equipment selection, analytic hierarchy process.

1. INTRODUCTION

Analysis of the drilling process involves knowing both what the actual drilling would mean and the important parameters of the process. From a theoretical point of view, drilling is the process of removing material from a surface, forming a cavity with a certain cross-sectional shape and which will in principle be used in the context of some assembly operations. Holes can have circular, polygonal or irregular cross-sections. Given the widespread use of holes in mechanical equipment, it is appreciated that the study of the drilling process is still important, although some drilling processes have been known for a very long time.

Drilling using a rotating cutting tool is the most well-known drilling method, but there are still milling, stamping, electrical discharge machining, electrochemical machining, water jet machining, laser beam machining, ultrasonic machining, plasma machining, blast drilling, friction drilling, etc.

Friction drilling uses the friction generated by the contact between a rotating tool pressed against the workpiece to produce heat, which will soften the workpiece material and, thus, as a result of a feed movement of the rotating tool, the material is removed and a cavity is gradually generated [1-4]. It is important to note that the tool must have a conical or spherical tip, so that the penetration of the tool into the workpiece is done gradually. Some rotary tooling solutions have, after the conical area, an area in the form of a truncated cone, of reduced taper, intended to finish the surface of the cavity being generated. Also, the workpiece material must meet the condition of having a melting temperature lower than the temperature that the friction in the process would be expected to achieve. Such materials can be aluminum, copper and their alloys, plastics, composite materials [1-4].

Friction drilling sometimes solves the problem of joints between sheets or strips, for example in aeronautics, where aluminum sheets are used. Using thin sheets, regular drilling with a drill is difficult, and screw assembly can also be complicated, due to the small contact surfaces. As such, it is appreciated that friction drilling allows a hole to be made more easily, and the removed material could form a bushing around the hole, thereby increasing the contact area of the plate with a screw or rivet. In the case of simultaneous drilling of 2 sheets to be assembled, the materials of the two sheets can be welded together, thus contributing to an increase in the rigidity of the assembly. Among the disadvantages of this process, it can be mentioned that there is a limited range of materials that can be drilled in this way, due to the condition that the melting temperature of the workpiece material is quite low. Friction drilling becomes more complicated when the workpiece has a greater thickness, which will make it difficult to move the plasticized material outward or make holes that are not pierced. Other possible disadvantages of the friction drilling process could be the appearance of microwelds between the material of the rotating tool and that of the workpiece, the possible development of an abrasion process, modification of the properties of the material around the hole due to the higher temperature (which can have a positive effect in the case of self-hardening materials, but also a negative effect, due to a possible increase in material fragility), the generation of chemical reactions or undesirable properties of the workpiece material. An important aspect is that friction drilling does not generate chips, which facilitates the development of the process, and that there is usually no need for chip evacuation and storage devices, as the chips are no longer a danger to the operator, to the machined surface or to the machine tool.

In this paper, it was proposed to analyze the constructive solutions of 3 devices with which friction drilling processes can be carried out and to select one of the solutions, using the AHP (analytical hierarchy process) method, of course depending on the criteria and requirements to be met. However, it is necessary, first, to consider some theoretical aspects of the friction drilling process and respectively to identify the three constructive solutions that can be used.

2. SELECTING A SOLUTION USING THE AHP METHOD

In current activities, the need may arise to choose an alternative among several possible alternatives, that is, to make a decision regarding a certain aspect, analyzing several solutions that could be considered. The elements of the decision process are *the objective of the decision*, *the decision-maker* or *decision-makers* (the people who make the decision), *the decision options* (or the alternatives to fulfill the objective), *the decision criteria*, *the coefficients of importance* and *the nature of the conditions*, i.e., if the conditions are of uncertainty, of risk or are deterministic (of certainty) [5].

Researchers have thought about how the process of selecting the best solution could be facilitated, and as such, several methods of solving such a problem have been proposed. Verzea was of the opinion that there can be *deterministic methods of decision-making*, under conditions of certainty, which are based on concrete, verifiable data and well-established rules [5]. The usable methods can be *deterministic methods* (Sum of Ranks method, Sum of Units method or AHP method). *A non-deterministic decision method* is a method that is used under conditions of risk or uncertainty and where the available data are not sufficiently clear. In this case, the solution is no single and clear, but rather a set of possible solutions, each with some associated probability. In general, non-deterministic methods take into account the variability and risks associated with different options and try to find solutions that optimize the chances of success or minimize losses in the context of uncertainty. Possible rules/methods to select a particular solution are Wald, Optimist, Hurwicz, Savage and Bayes-Laplace.

In this work, the deterministic method AHP, (Analytic Hierarchy Process) will be applied. The method will be used to identify the most appropriate device capable of performing friction drilling and also allow the identification of correlations between the magnitude of the axial force during the friction drilling process and the feed speed of the rotating tool in the workpiece material. At the base of the method, there are mathematical and psychological considerations, the method taking into account a multi-criteria analysis, in which the selection criteria are compared with each other, two by two, with the help of matrices and, finally, the solution that best corresponds to the conditions is highlighted. The one who proposed the method was professor Thomas Saaty, who can be mentioned as an inventor, architect and professor at the University of Pittsburgh (USA) and that he was also the promoter of another analysis method (ANP - Analytic Network Process) [6].

The AHP method has been a concern for researchers to solve different categories of problems [6-12].

Thus, Stofkova et al. emphasized the importance of using the AHP method for making a strategic managerial decision. They sought to identify an effective method for a ranking based on certain criteria considered [7]. They also looked at several ways to use the method and its advantages.

González-Prida carried out a deeper analysis of some critical aspects in the maintenance or management area that arises after the sale [8]. He considered identifying several relevant solutions for different time frames. The researcher proposed, as such, a new name for the analysis method, namely the DAHP (Dynamic Analytic Hierarchy Process) method.

A group of researchers coordinated by Katharina Schmidt analyzed a number of 121 articles related to the AHP method, concluding that the analysis method is somewhat at the beginning of its use in the field of health and research should still be continued, including on the efficiency and how of using the method in different situations and for different application conditions [9].

Andrade Longaraya et al. highlighted some possibilities of using the AHP method in the sector of companies that provide services, resorting to the analysis of the activities of 158 subsidiaries of some companies in Brazil. They still highlighted the barriers and limits to the application of the method, which they consider an effective tool in the management decision-making process [10].

Darmantya referred to the use of the AHP method in choosing an Internet provider, using 2 levels of criteria [11].

A team of researchers from the "Gheorghe Asachi" Technical University in Iasi used the AHP method to select a technical solution for testing the ability of materials to be used in the manufacture of parts by injection molding [13].

Another work also developed by a group from the "Gheorghe Asachi" Technical University in Iași presents the results of some research related to the identification of a solution for a friction drilling device and which would allow the highlighting of the influence exerted by the axial force on the speed of penetration of tools in the workpiece, when friction drilling with constant feed force are used [4].

The main steps that can be used when applying the AHP method are as follows [6]:

1. Modeling the problem, revealing the objective pursued, the available alternatives and the criteria for evaluating the alternatives;

2. Establishing priorities, by making comparisons of alternatives two by two;

3. Elaboration of a synthesis that includes the ranking of alternatives;

4. Checking the consistency of assessments;

5. Establishing the final decision.

3. USABLE CONSTRUCTIVE SOLUTIONS FOR ESTABLISHING A CORRELATION BETWEEN THE MAGNITUDE OF THE AXIAL FORCE AND FEED RATE IN FRICTION DRILLING

Friction drilling uses the heat resulting from the friction between the conical tip of a rotating tool and the workpiece to bring the workpiece material into a plastic state and push it away from the workpiece in the direction of the feed motion (fig. 1).

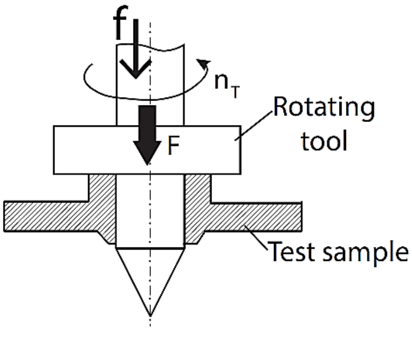

Figure 1. Schematic representation of the friction drilling process

The processing scheme therefore implies the existence of a rotation movement n_t of the tool, a forward movement *f* along the tool axis and respectively a force *f* to move the material of the workpiece in a plastic state, as a result of the pressure exerted by the conical tip of tools.

Three constructive solutions were considered, able to ensure, first of all, the fulfillment of the condition of facilitating the obtaining of some information regarding the correlation between the magnitude of the axial force required to make a hole by friction in a test sample made of a certain material and the speed *f* of penetration of the rotating tool into the workpiece material.

Thus, in the case of a first solution, it was resorted to the placing the electric motor for driving the rotating movement of the tool on a sled that can move freely on a vertical guide (fig. 2).

A platform is solidarized to the sled on which there will be some weights of different values, capable of generating axial feed forces *F* of distinct sizes.

A workpiece in the form of a plate is clamped with the help of clamps, screws and supports on the table of a drilling machine that has the possibility of moving the tool carrier slide along a vertical direction.

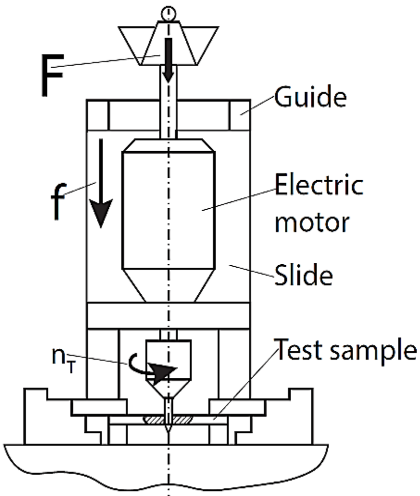

Figure 2. Friction drilling device that considers the use of a bench drilling machine

A second solution considered was the use of a universal tensile-compression testing machine (fig. 3). A device that takes some of the elements mentioned in the case of the previous solution (electric motor, sled that can move on a vertical guide, etc.) could be placed on the table of the universal tensile-compression testing machine, while the feed force *F* will be exerted by the mobile cross slide of this machine.

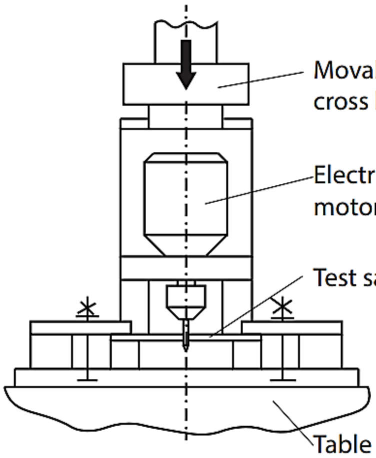

Figure 3. Friction drilling device adaptable on a universal tensile-compression testing machine

Usually, universal tensile-compression testing machines are equipped with subsystems that transmit to a computer information on the force applied to the test sample and the amount of deformation of the test sample. The information is highlighted using a specialized software, allowing the gradual development of a force-displacement or stress-strain diagram.

In the case of the solution presented here, such a diagram could operationally highlight the variation in force magnitude during friction drilling. By imposing an axial feed rate *f* of known magnitude, the variation of the magnitude of the axial force *F* during the working stroke of the mobile crossbar, until the complete perforation of the specimen, can be highlighted. The third constructive solution is based on the use of a column drilling machine (fig. 4). The force *F* required for drilling is provided by moving the main shaft of the drilling machine at a predetermined feed rate.

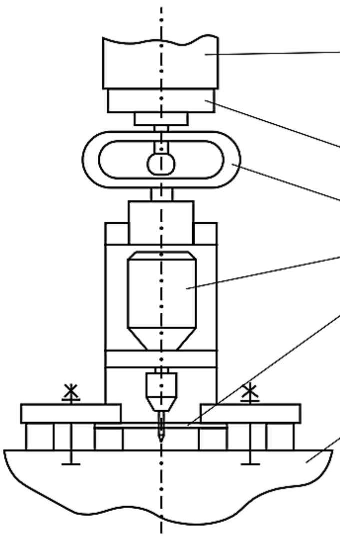

Figure 4. Friction drilling device adaptable on a column drilling machine

. This force *F* will be transmitted to the slide of the friction drilling device by means of a dynamometer, which will highlight the evolution of the magnitude of the axial force *F* during friction drilling. To avoid rotation of the dynamometer during the experimental test, an axial bearing was placed between the dynamometer and the front surface of the main shaft.

4. THE USE OF THE AHP METHOD TO SELECT A CONSTRUCTIVE SOLUTION USABLE FOR STUDYING THE EVOLUTION OF THE AXIAL FORCE IN FRICTION DRILLING

The objective pursued was to identify an equipment that can be used to highlight the correlation between the size of the cutting force and the feed rate of the rotary tool in the case of a friction drilling process of some test samples made of certain materials. In figure 5, it can see the hierarchical relationships between the components under analysis.

As previously mentioned, it is necessary, in principle, to materialize two stages, namely the comparison of the evaluation criteria of the considered solutions and, subsequently, the analysis of the alternatives by comparison with the help of each of the established criteria.

4.1. Comparison of criteria

In table 1 it can see the result obtained by comparing the criteria two by two, to establish their order of importance. Basically, the elements in the first column are successively compared with the elements in the first line of the table. Obviously, in the cells along the descending diagonal of the matrix corresponding to the data in the table, the comparison of a criterion with itself is taken into account and, as such, the number 1 will be entered in the respective cells. The scoring scale used is the one proposed by professor Saaty [6]:

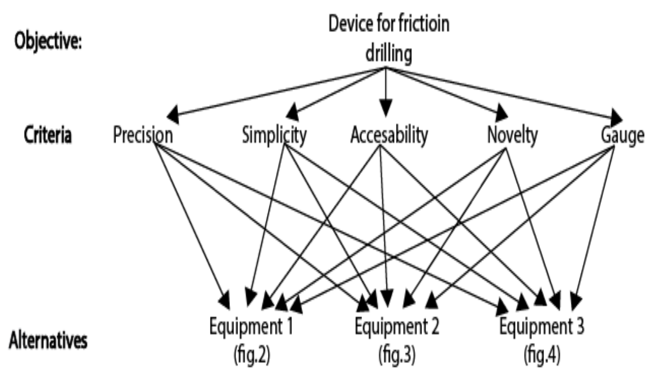

Figure 5. Hierarchical relationships in the problem of identifying a suitable device

1- equal importance;

3- a criterion is less important in relation to the one with which it is compared;

5- a criterion is more important in relation to the one with which it is compared;

7- a criterion is very important in relation to the one with which it is compared;

9- a criterion is extremely important in relation to the one with which it is compared;

Values 2, 4, 6, 8 correspond to intermediate situations, in relation to those previously mentioned.

The values in the matrix represented by table 1 are completed according to the options of the person who wants a solution and who formulates a certain prioritization of the criteria to solve the problem addressed.

To further justify and clarify the choice of certain values when comparing criteria, it is important to state the conditions taken into account and what was sought by them.

Thus, it was considered that the analysis is carried out from the point of view of a researcher - student who has to solve the problem addressed within a bachelor's thesis or the activities of a student scientific circle or of other research work.

All the machines and devices necessary for the materialization of the finally selected alternative are considered to already exist in equipping laboratories and workshops in the faculty.

The accuracy criterion refers to the hole diameter tolerance that friction drilling can provide using each of the alternatives considered.

The criterion related to *simplicity* takes into account the number of components and devices that must be mounted on the equipment, to apply the friction drilling process and to analyze the values of the output parameters of the investigated process.

The accessibility criterion was formulated from a researcher's point of view: a machine that requires training to use will be less accessible, and the person responsible for using that machine may not allow direct access to the student except in the presence of a specially trained person who could be involved in performing the tests together with the student.

The novelty criterion refers to the degree of originality and creativity corresponding to each alternative. Finally, *the gauge criterion* was adopted to take into account the space occupied by the equipment and possibly the time required to prepare the equipment to carry out a friction drilling process. Limited available space could make equipment preparation more difficult.

Table 1. Comparison of criteria

Criteria	Accuracy	Simplicity	Accesibility	Novelty	Gauge
Precision	1	3	1/2	7	5
Simplicity	1/3	1	1/5	5	3
Accessibility	2	5	1	7	5
Novelty	1/7	1/5	1/7	1	1/3
Gauge	1/5	1/3	1/5	3	1
Sum	3.676	9.533	2.043	23	14.33

By considering the data in table 1, the decision matrix can be developed, by writing the relationship (1).

$$[A] = \begin{bmatrix} 1 & 3 & 0.5 & 7 & 5 \\ 0.333 & 1 & 0.2 & 5 & 3 \\ 2 & 0.25 & 1 & 7 & 5 \\ 0.143 & 0.2 & 0.143 & 1 & 0.333 \\ 0.2 & 0.333 & 0.2 & 3 & 1 \end{bmatrix} \quad (1)$$

It is still necessary to develop the matrix of normalized relative weights $[A]_n$, in which each element of the matrix will be divided by the sum of the values in the respective column existing in table 1. This leads to:

$$[A]_n = \begin{bmatrix} 0.272 & 0.314 & 0.245 & 0.304 & 0.349 \\ 0.09 & 0.105 & 0.098 & 0.217 & 0.209 \\ 0.544 & 0.026 & 0.489 & 0.304 & 0.349 \\ 0.039 & 0.021 & 0.07 & 0.043 & 0.023 \\ 0.054 & 0.035 & 0.098 & 0.13 & 0.07 \end{bmatrix} \quad (2)$$

The next step consists in identifying the priority vector *w*, which is determined by summing the elements on each line and dividing the sum by the number of criteria, i.e., calculating the arithmetic mean corresponding to each column:

$$w = \frac{1}{5}\begin{bmatrix} 1.484 \\ 0.719 \\ 1.712 \\ 0.196 \\ 0.387 \end{bmatrix} = \begin{bmatrix} 0.297 \\ 0.144 \\ 0.342 \\ 0.039 \\ 0.077 \end{bmatrix} \quad (3)$$

With the help of this vector, the weight of each criterion can be highlighted and the ranking of the criteria can be resorted to, giving each criterion an order number, as can be seen in table 2.

Table 2. Weights and ordinal numbers of the criteria taken into account

Criterion number	Criterion	Weight	Rank
1	Precision	29.7%	2
2	Simplicity	14.4%	3
3	Accessibility	34.2%	1
4	Novelty	3.9%	5
5	Gauge	7.7%	4

The evaluation of the consistency of the obtained results is carried out with the help of a consistency index *CI* (table 3) and the consistency ratio *CR*, to see a admissible value lower than 10%.

To determine the value of the index, it initially needs to calculate *the main eigenvalue* λ_{max}, which is considered equal to the sum of the product as an element of the priority vector and the sum of the values in each column of table 1:

$$\lambda_{max}=0.297\cdot 3.676+0.144\cdot 9.533+0.342\cdot 2.043+0.039\cdot 23+0.077\cdot 14.333=5.164 \quad (4)$$

The formula for calculating the consistency index *CI* is as follows [6]:

$$CI = \frac{\lambda_{max}-n}{n-1} A = \pi r^2, \quad (5)$$

where n represents the number of criteria. In the analyzed case, n=5 and, therefore:

$$CI=\frac{5,164-5}{4}\cdot 100\%=4.1\% \quad (6)$$

Using the information from table 3, from which the value of the average random consistency index *RI* corresponding to the analyzed case (n=5) is determined, the consistency ratio is calculated:

$$CR=\frac{CI}{RI}=\frac{0.041}{1.12}=0.037=3.7\%<10\%, \quad (7)$$

The result obtained is within the limits of the admissible range of consistency index.

Table 3. Suggested values for the random consistency index *RI* [13]

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4.2. Analysis of alternatives

The three considered solutions described in chapter 4 are further analyzed successively using each criterion separately. The way of working is similar to the one used for the analysis of the 5 criteria, only this time the software will be used that allows for quick calculations [14-17].

The results of considering the first criterion (precision) were entered in tables 4 and 5.

Table 4. Comparing alternatives using the precision criterion

Analyzed solutions	Solution 1	Solution 2	Solution 3
Solution 1	1	1/9	1/4
Solution 2	9	1	5
Solution 3	4	1/5	1

With the help of software used, it is found that the consistency rate is 7.4%, which is part of the acceptable range (below 10%). The other values of interest are λ_{max} = 3.071, *CI*=0.0048, *RI*=0.065.

Table 5. Weights and order numbers of the solutions, determined using the precision criterion

Current nr.	Solution	Weight	Rank
1	1	6.3%	3
2	2	74.3%	1
3	3	19.4%	2

As a result, the solution using the tensile-compression testing machine will be considered the most accurate, which was also expected, due to the inclusion of a computer in the testing equipment, which performs the necessary calculations for the development just during testing a force-displacement diagram and by means of which the feed rate of the rotary tool is determined.

As previously described, the solutions will also be analyzed through the other 4 criteria (tables 6, 7, 8 and 9).

Table 6. Comparing solutions in terms of simplicity

Solution	Solution 1	Solution 2	Solution 3	Weight	Rank
Solution 1	1	1/8	1/4	6.8%	3
Solution 2	8	1	5	73.3%	1
Solution 3	4	1/5	1	19.9%	2
CR=9.8%, λ_{max}=3.094, *CI*=0.0047, *RI*=0.048					

It can be mentioned that the complexity of the other 2 proposed solutions takes into account the need to experimentally determine the duration of the drilling process, to be able to calculate the feed speed *f*, but also the need for a set of weights to materialize different values of the feed force *F*.

In the case of the second solution, one more dynamometer is needed to highlight the magnitude of the axial force, while the first solution only requires a coaxial location of the direction of force *F* action in the direction of the feed movement.

Table 7. Comparison of solutions with the help of the accessibility criterion

Solution	Solution 1	Solution 2	Solution 3	Weight	Rank
Solution 1	1	9	4	70.8%	1
Solution 2	1/9	1	1/5	6.0%	3
Solution 3	1/4	5	1	23.1%	2
CR=7.4%, λ_{max}=3.071, *CI*=0.0048					

Accessibility in this case is obvious for the equipment that uses a plate on which the weights will be placed to materialize the feed force *F*.

It will be much easier for the student - researcher to understand the process, to operate the machine, and he should not call for additional specialized personnel, but supervision will be required from the point of view of occupational safety.

Table 8. Comparison of solutions using the novelty criterion

Solution	Solution 1	Solution 2	Solution 3	Weight	Rank
Solution 1	1	1/8	1/3	7.5%	3
Solution 2	8	1	5	74.2%	1
Solution 3	3	1/5	1	18.3%	2
CR=4.6%, λ_{max}=3.044, *CI*=0.0049					

It can be concluded that the drilling solution with the help of a tensile-compression testing machine is characterized by a higher degree of novelty, making it, moreover, the object of an action to elaborate a patent application.

Table 9. Comparison of solutions using the gauge criterion

Solution	Solution 1	Solution 2	Solution 3	Weight	Rank
Solution 1	1	9	2	58.9%	1
Solution 2	1/9	1	1/8	5.4%	3
Solution 3	1/2	8	1	35.7%	2
CR=3.9%, λ_{max}=3.037, *CI*=0.0049					

The analysis of the information in table 9 highlights the fact that, from the point of view of the size criterion, the first solution also proves to be more advantageous.

Having completed the analysis of the solutions by using each of their evaluation criteria, a record of the results was made in table 10.

The overall composite weight (denoted by Gen. weight in table 10) must be calculated to determine which of the proposed solutions is the most convenient.

The general composite weight indicator is calculated for each proposed solution, it being a sum of the results of multiplying the weight of each criterion with the weights of the solution when using that criterion.

Table 10. Final evaluation of solutions

Criterion	P	S	A	N	G	Gen. weight	Rank
Criterion weight	0.297	0.144	0.342	0.039	0.077		
Solution 1	6.3%	6.8%	70.8%	7.5%	58.9%	31.89%	2
Solution 2	74.3%	73.3%	6.0%	74.2%	5.4%	37.98%	1
Solution 3	19.4%	19.9%	23.1%	18.3%	35.7%	19.99%	3
Sum	100%	100%	99.9%	100%	100%	89.86%	

.

According to the results listed in table 10, the most convenient alternative corresponds to solution no. 2. To determine the consistency of the answer we obtained, the general consistency of the established hierarchy is calculated:

$$\overline{CR} = \frac{\sum_i w_i CI_i}{\sum_i w_i RI_i} \quad (8)$$

$$\overline{CR} = \frac{0.041\cdot1+0.0048\cdot0.297+0.0047\cdot0.144+0.0048\cdot0.342+ +0.0049\cdot0.039+0.0049\cdot0.077}{1.12\cdot1+0.58\cdot0.297+0.58\cdot0.144+0.58\cdot0.342+0.58\cdot0.039+ +0.58\cdot0.077} = \frac{0.045}{1.64} = 0.027 = =2.7\%<10\% \quad (9)$$

It turns out that it is dealing with a good consistency. To clarify the way in which the calculations were performed, it can be mentioned that the sum of the products between the elements of the priority vector *w*, calculated in the criteria analysis stages, and the consistency indices *CI*, calculated in the analysis of the alternatives by using each criterion was entered at the numerator of the fraction of evaluation. The first element corresponds to the consistency index determined when analyzing the evaluation criteria. In the denominator, the first term is the random consistency index *RI*, highlighted in table 3 and characteristic for 5 elements, the other terms representing the product of the coefficient *RI*=0.58 characteristic for 3 elements, i.e., for the 3 alternatives, and also the elements of the initially calculated weight vector.

The good consistency obtained proves that the steps taken can be appreciated as having a good level of credibility, coherence and logic.

5. CONCLUSIONS

Friction drilling is the process of generating cavities using the heat produced by friction to soften the material of the workpiece and evacuating some of the softened material of the workpiece by feeding the rotating tool, which also has a specific conical shape.

As a rule, friction drilling is used when simple drilling with a drill or other type of drilling is more complicated and does not have more convenient features than friction drilling. However, friction drilling is not very widespread due to the need for more expensive equipment. The areas where applications of friction drilling are encountered are those of aeronautics, where friction drilling is a solution for the assembly of thin aluminum plates and the manufacture of steel cabinets, respectively, when a large number of holes is needed, and this friction drilling it is the fastest process and when no chips are generated during drilling.

In specialized literature, friction drilling is a well-known process, with research results related to this process being presented. However, it is appreciated that research is still needed to aim at widening the range of applications and variants of the method, as it is possible to improve the process or at least some less convenient aspects of it.

The present work aimed to carry out an analysis to identify the best alternative for friction drilling, among three alternatives based on the use of specific equipment. The identification of alternatives and the ranking of the equipment evaluation criteria considered relevant was carried out using the analytical hierarchy process (AHP) method.

It is appreciated that the selected solution meets the initial requirements, providing the most complete and accurate information on friction drilling. Although it has some disadvantages compared to the other alternatives, as observed in the analysis carried out, those disadvantages are of lesser importance. It is intended that in the next period the validity of some hypotheses will be verified through a practical check on a tensile-compression testing machine.

Another possible continuation of the research could consider the use of a machine equipped with a numerical control subsystem, on which several holes could be made, with the use of different values of some of the input factors in the friction drilling process. Interesting aspects could also result from the study of the behavior of distinct materials in the friction drilling process. Designing and making specialized friction drilling equipment would also be a possible future research direction.

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