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# CORRELATION BETWEEN MACHINABILITY BY CLASSICAL MACHINING METHODS AND USE OF NONCONVENTIONAL TECHNOLOGIES

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ABSTRACT: Between the machinability by classical machining methods and use of nonconventional technologies there is a certain correlation. When the machining by classical methods is not possible or it is difficult to be applied, one can took into consideration the use of nonconventional technologies. The documentary research showed that that the empirical models corresponding to the tool wear, cutting forces and roughness of the machined surface, considered also as machinability indexes, take into consideration characteristics of the workpiece material. In order to improve the conditions of developing a machinability evaluation by drilling under constant force feed, a machining schema involving the work feed movement of the test piece from up to down, to the rotating drilling tool, was proposed. The experimental research led to a power type empirical mathematical model able to highlight the influence exerted by the rotation speed, drilling tool diameter and the force feed on the length of hole achieved in a certain time.

KEY WORDS: machinability by classical machining methods, nonconventional technologies, machinability indexes, drilling under constant force feed, empirical mathematical model

## 1. INTRODUCTION

Machining technology refers to the processes, methods, rules, procedures, operations and technical conditions which could be applied in order to obtain a certain industrial product.

If one takes into consideration the workpiece mass changes during the manufacturing process, one can find that there are manufacturing methods based on material removal from workpiece *(subtractive manufacturing methods),* manufacturing methods based on adding material to workpiece *(additive manufacturing methods),* and manufacturing methods which do not involve significant changes of the workpiece material mass. In the group of the subtractive manufacturing methods, one can found manufacturing methods based on cutting processes, plastic deformation processes, erosion processes etc.

Within the cutting machining methods, a possible classification could take into consideration the direction of the movements achieved by cutting tool or workpiece. Thus, in the case of turning processes, the workpiece achieves a rotation main movement around its axis, while the cutting tool achieves a feed movement along a direction placed in a surface perpendicular on the rotation axis of the workpiece. In the case of drilling process, the tool (on drilling machine tools) or the workpiece (on lathes) materializes the main rotation movements, while the drilling tool and/or workpiece achieves a feed movement, along a direction parallel to the direction of rotation axis. There are also cutting processes characterized by rectilinear main movements and feed movements achieved by cutting tool and/or by workpiece (planning, slotting etc.), as there are cutting processes in which there is a circular feed movement (grinding, manufacturing of gears teeth etc.).

The so-called *nonconventional machining processes* involves usually a supplementary energy transfer to the work zone so that either a classical machining process develops in more convenient conditions or the machining process develops on the base of new principles, fundamentally distinct in comparison with the principle of plastic deformation, which is the principle applied in case of cutting processes (turning, milling, drilling, grinding etc.) or processes based on material change as a direct consequence of a plastic deformation process (drawing, cutting etc.). If the phenomena found at the base of material removal is taken into consideration, one can notice that there are nonconventional machining methods which use electrical discharges (electrical discharge machining), chemical or electrochemical reactions (chemical machining, electrochemical machining), ultrasonic vibrations (ultrasonic machining), plasma beam (plasma beam machining), laser beam (laser beam machining), electron beam (electron beam machining) etc.

Essentially, the nonconventional machining processes are used when the workpiece material is hard enough or the surface to be obtained is too complex, so that the application of one of the classical machining methods is not possible or it is possible, but in less convenient conditions.

As one can notice, a case when the nonconventional machining methods are applied is when the machinability of workpiece material by classical machining methods is too low, so that it is not possible or it is not convenient to apply the classical machining methods.

The machinability of a material by a certain classical machining method can be defined as the material technological property able to ensure to the material a machining process more convenient for the part producer: with high machining speed, but with a low cutting tool wear, with a low mechanical and energetical solicitation of the mechanical machining system, with the obtaining a low roughness of the machined surface, a convenient shape of chips etc.

The above mentioned definition shows that there are distinct criteria and methods able to offer an image concerning the machinability of a material by classical machining methods:

- methods and criteria based on the information about the tool wear;
- methods and criteria based on the information concerning the forces and moments generated during the machining process or the energy consumption during the machining process;
- methods and criteria which take into consideration the values of parameters characterizing the roughness of the machined surface;
- methods and criteria based on information referring to the shape and other characteristics of chips detached from the workpiece material etc.

It is important to have information concerning the machinability of a material by distinct machining methods since in such a case, an optimal selecting and establishing of the machining parameters values is possible; the technology designer can also determine adequate cutting tools, devices and machines tools. One can conclude that the information concerning the material machinability facilitates the activities directed to the machining process optimization.

The link between the machinability of materials by distinct machining methods and the nonconventional machining methods was studied by the researchers in the field of manufacturing technologies.

Thus, in 1989, Rhoades showed [7] that the non-traditional machining processes were able to provide productivity improvements, especially in the case of difficult-to-machine materials and complex geometric shapes; he mentioned the possibility to use electrical discharge machining, electrochemical machining, ultrasonic machining, orbital abrasive machining, laser beam machining, electron beam machining, abrasive water jet, abrasive flow machining.

El-Hofy addressed the problem of evaluation of machinability in the case of common engineering materials by conventional and nonconventional methods [1]. He appreciated that among the factors to be considered when selecting a machining process, there are the properties of the part material and these aspects practically characterize the material machinability.

Karaguzel et al. [3] noticed that an increase of the tool life of difficult-to-cut materials is possible using nonconventional turning processes. Even the machining processes studied by them (turn-milling and rotary turning) could be considered as advanced classical machining methods (since they are based on processes of chips generation as a consequence of a plastic deformation of the workpiece material by the cutting tool teeth), one can notice the recommendation to use nonconventional machining methods in the case of difficult-to-cut materials.

Problems of machinability by some nontraditional machining methods were approached by the authors of distinct chapters included in a monograph edited by Hocheng and Tsai; they noticed that the appearance of new materials characterized by improved mechanical properties determined an intensification of researches concerning the use of non-traditional machining processes [2].

Sidda Reddy et al. [8] considered that in the case of the nickel based alloys, the nickel-iron-chromium alloy Inconel 800H shows a poor machinability and for this reason they proposed the use of a nonconventional machining method (abrasive water jet machining) to process it.

Pradeep Kumar et al. appreciated [6] that the selection of optimum process parameters could be considered as time consuming and costly process. For this reason, researches concerning the selection of optimum process parameters must be developed. They investigated the machinability of stainless steel 316 by electrical discharge machining using brass electrodes.

Mascenik and Gaspar developed and experimental research concerning the influence by distinct factors exerted on the roughness and microhardness of surfaces obtained by some nonconventional cutting methods (laser beam cutting, plasma beam cutting, water jet cutting) [5].

## 2. PREMISES FOR HIGHLIGHTING THE CONDITIONS IN WICH THE NONCONVENTIONAL TECHNOLOGIES ARE USED

A schematic of machining by cutting could be observed in figure 1. One can see that in the first stage, under the action of cutting tool found in a relative movement to the workpiece, a high pressure is exerted on a certain zone of the workpiece material up to the moment when the shearing resistance of this material is exceeded and the development of a shear plane determines practically the separation of a chip. If the workpiece material is ductile enough, the continuation of the cutting process lead to a continuous chip, while if the workpiece material is brittle, one can observe the generation of interrupted chips.

The cutting machining method is mandatory accompanied by the generation of cutting forces and moments. In the case of machining schematic from figure 1, one took into consideration the decomposition of the machining force exerted on the workpiece material in components placed along an orthogonal axes system and, thus, the components $F_x$, $F_y$ and $F_z$ could be highlighted.

Both the general relationship for the cutting force and the relation valid for the components of the cutting force can be generally written as functions of the work feed $f$, depth of cut $a_p$ and workpiece material Brinell hardness $HB$:

$$F = C_F a_p^{x_F} f^{y_F} HB^{n_F}, \qquad (1)$$

where $C_F$, $x_F$, $y_F$ and $z_F$ are a coefficient and exponents whose values could be established by considering the workpiece material and other machining conditions, but they could be appreciated as offering information about the workpiece material machinability from the point of view of cutting forces.

It is clear that the sizes of the cutting force components are dependent on the workpiece material properties and this means that the cutting force size could be appreciated as offering information concerning the workpiece material machinability by cutting. As the workpiece material is characterized by high mechanical properties, the necessary cutting forces increase also and there will be a stage when the classical machining methods could not be applied or their use is not convenient.

On can notice also that as a consequence of the cutting process, after the cutting tool, a new – machined – surface appeared. This surface can be characterized by geometrical and physical properties. Both geometrical and physical properties of the surface layer obtained by cutting are strongly influenced by the workpiece material properties. For example, one can write the relation valid for the surface roughness parameter $Ra$ (arithmetic mean deviation for the assessed profile) in the case of turning a test piece made of steel:

$$R_a = C_0 v^{C_1} f^{C_2} r_\varepsilon^{C_3}, \qquad (2)$$

where the coefficient $C_0$ and the exponents $C_1$, $C_2$ and $C_3$ have values which depend on the nature of the workpiece material. This means that the roughness of the machined surface could be also considered as an indicator of material machinability and the surface roughness could be analyzed as a machinability index.

The aspects specific to the cutting process phenomena (the way in which the chips are generated, as a consequence of the material removal from the workpiece especially by mechanical phenomena), the roughness of the machined surface could not be diminished under certain values, specific, in fact, to each cutting machining process. The necessity to decrease the size of the surface roughness led to searching new or improved machining methods and such a situation determined, for example, the appearance and development of certain non-conventional machining methods, able to ensure obtaining low roughness of the machined surfaces.

One knows also that the phenomena (friction, heat, abrasion etc.) developed in the contact zone between the cutting tool active surface and the chip on the one hand, and machined surface on the other hand determines the gradually evolution of a wear

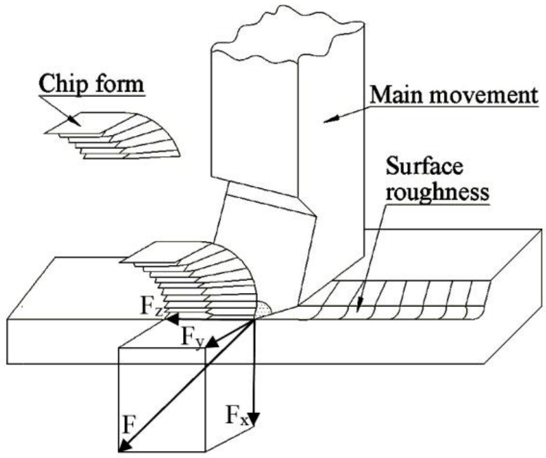

**Figure 1.** Machinabillity indexes specific to a classical machining methods

phenomenon, materialized by a gradual removal of material from the cutting tool and sometimes by a plastic deformation of the cutting tool corner. It is clear that the evolution speed of the cutting tool wear depends in a large extent on the mechanical and physical properties of the workpiece material.

In order to evaluate the cutting tool relative wear, V. I. Komissarov proposed [11] the use of the following empirical relationship:

$$U_{rv}=C_u v^m f^n a_p^p k_\alpha k_\gamma k_r \tag{3}$$

where $C_u$ is a coefficient whose value is established taking into consideration the nature of the machined material, $v$, $f$ and $a_p$ are the cutting speed, work feed and depth of cut, $k_\alpha$, $k_\gamma$ și $k_r$ are exponents whose values depends on the values of geometrical parameters of the cutting tool (clearance angle $\alpha$, back-rake angle $\gamma$, corner radius $r_\varepsilon$) and $m$, $n$ and $p$ are exponents experimentally established. One can see that the value of the coefficient $C$ practically offers an image concerning the workpiece material machinability, if the cutting tool wear criterion is considered.

From the above mentioned considerations, one can conclude that the cutting tool wear could be considered as a machinability index. If the mechanical and physical properties of the workpiece material are high enough, it is possible that this material could not be machined by classical machining methods or the use of the classical machining methods could not be convenient, just due to the intense wear affecting the cutting tool active surfaces. This could be a situation when the problem of using nonconventional machining methods could be formulated.

One can conclude that when the indexes of machinability by classical machining methods have not convenient values, other machining methods have to be applied and a solution able to solve this problem was the application of the so-called *nonconventional machining technologies.*

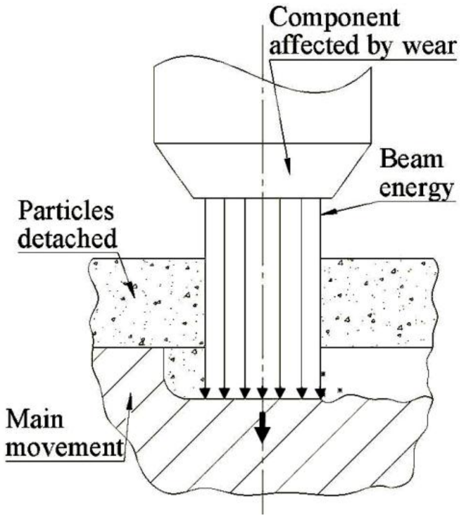

**Figure 2.** Machinability indexes valid in the case of a nonconventional machining method

A schematic valid in the case of nonconventional machining methods is presented in figure 2. One can see that in such a situation, essentially there is a work movement between workpiece and a high energy beam focused on the surface to be machined. As a consequence of the energy transfer to a certain zone of workpiece, a thermal, chemical or mechanical phenomenon develops and a material removal from workpiece could be observed. Changing the values of the process input parameters, one can control the values of the parameters of technological interest: material removal rate, tool wear, roughness of the machined surface, thickness of the layer affected by the machining process etc.

In the case of the most nonconventional machining processes, there is not an intense mechanical solicitation of the technological system and this means that with some exceptions, the sizes of the machining forces are not considered as indexes of machinability.

There are nonconventional machining processes in which a proper tool is not used and this means that there is not a proper tool wear, but specific aspects of other components wear could be discussed. For example, in the case of electrical discharge machining, there is a tool electrode wear, but in the case of the electrochemical machining, practically there is not a tool wear process. However, in this last case (electrochemical machining process), one can signalize a change of the work liquid (electrolyte) characteristics which can be addressed as a wear process. In the case of laser machining process, the laser beam could be considered as a tool and it is clear that this tool could not be affected by a wear process; however, one can mention a wear process able to affect other components of the technological system, but up to now, this wear was not considered as an index of workpiece material machinability by laser beam machining.

## 3. FACTORS ABLE TO EXERT INFLUENCE ON THE VALUES OF MACHINABILITY INDEXES

There are many groups of factors able to exert influence on the values of machinability indexes. Some of these groups are the following:

- chemical composition and metallurgical structure of workpiece material;

- mechanical properties of workpiece material (tensile strength, hardness, elongation per unit length etc.);
- physical properties of the workpiece material (melting and boiling temperatures, thermal conductivity, specific heat etc.);
- nature and properties of the tool material (tensile strength, melting temperature, temperature of phase change, friction coefficient with the workpiece material etc.);
- geometrical parameters of tool active part;
- values of the machining parameters (machining speed, work feed, depth of cut);
- presence and properties of cutting fluid, if such a fluid is used;
- rigidity of technological system on which the values of machinability index are determined;
- characteristics of vibrations which accompany the process of machinability evaluation.

A systemic analysis could be developed in order to identify the factors able to exert influence on the values of machinability indexes within a process of machinability evaluation. One knows that the systemic analysis considers the process as a system, with input and output factors and a detailed systemic analysis could better highlight the correlations among the input factors and output parameters of machinability evaluation (tool wear, forces generated by the machining process, roughness of machined surface, characteristics of the particles detached during machining process etc.).

## 4. MACHINABILITY EVALUATION BY DRILLING UNDER CONSTANT FORCE FEED

The use of the machining force criterion in order to evaluate the machinability by drilling highlights two possible directions of applying:

- measurement of the force size, under constant feed speed. Usually, adequate dynamometers are used by means of which the values of the machining force could be determined;

- measurement of the feed size, under constant feed force. Not only the feed size can be used as a machinability index. The researchers showed that within such a method of machinability evaluation, other indexes could be also determined: the length of the machined surface in a certain time, the number of revolutions achieved by tool or by workpiece in a certain time, the energy consumed for obtaining a certain machined surface etc.

It is known a method of metallic material machinability evaluation based on the use of a constant feed force. Essentially, a plate supporting a weight of known size is attached to the feed assembly, so that that weight generates the feed force. Such a machining schema could be applied on workshop drilling machine or on other type of drilling machine based on the use of a vertical feed movement of the drilling tool to the test piece.

The main disadvantage specific to such a machining schema for evaluation of the machinability under constant feed force derives from the accumulation of the chips in the space between the tool (practically, in the channels existing in the drilling tool) and the surface obtained by machining. These small chips generate supplementary friction forces and moments, and, in this way, the results of the machinability test could be affected. The results will not reflect strictly the machinability of the investigated material, but also the friction phenomena developed among the drilling tool, the chips detached from the workpiece material and the wall of the hole generated by drilling process.

In order to diminish the influence exerted by the above mentioned friction phenomena, the machining schema from figure 3 was taken into consideration. One can see that in the case of this machining schema, one uses a feed movement of the test piece, from up to down, to the drilling tool placed under the workpiece and found in a rotation movement. In this way, it is expected that the chips could be removed just under their gravity force, the chips evacuation could be accelerated, and the machinability indexes determined could be affected in a low extent by the presence of chips.

The above described machining schema was materialized [4] on a workshop drilling machine type Proxxon. A vice was assembled on the feed slide of the drilling machine and the test piece was clamped in this vice. A plate supporting a weight of known size was also assembled to the feed slide. On the other hand, an adequate electric motor for

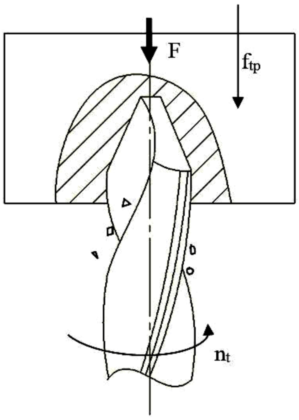

**Figure 3.** Machining scheme corresponding to the evaluation of the machinability by drilling under constant force feed

achieving drilling and milling processes was clamped on the machine tool table and on the main shaft of the electric motor a chuck was assembled. Drilling tools with distinct diameters ($d_1$=1 mm and $d_2$=2 mm) were clamped in the chuck. In order to develop an experimental factorial test with three independent variables at two levels, two distinct weights were successively placed on the plat, determining two distinct axial feed forces. The third input factor was the rotations speed of the drilling tool ($n_1$=1331 rev/min and $n_2$=2150 rev/min).

Since the force generated by the weights placed on the plate is not coaxially positioned to the drilling tool, a calibration operation was materialized, using a standard dynamometer placed between the test piece and the drilling machine table. In this way, one knew the drilling force generated by each weight placed on the plate attached to the feed slide ($F_1$=3.681 daN and $F_2$=4.395 daN).

As a consequence of the mathematical processing of the experimental results, power type empirical models were determined. For example, in the case of test pieces made of steel 1C45, the following empirical mathematical model valid for the depth of the machined hole $h$ was determined:

$$h = 1.538 \cdot 10^{-7} d^{1.311} F^{8.977} n^{0.362} \tag{4}$$

where $d$ [mm] is the diameter of drilling tool, $F$ [daN] – feed force and $n$ – number of drill revolutions per minute. One can see that the most significant influence on the depth of obtained hole was exerted by the feed force, whose exponent in the relation (4) has the highest value, in comparison with values of the exponents attached to the other two input factors.

## 5. CONCLUSIONS

The machinability by cutting of a certain material is a technological property which shows the ease to machine the material in conditions more convenient for the producer. There are many distinct criteria for machinability evaluation. When the machinability by classical machining methods is low, the problem of applying the so-called nonconventional machining methods can be formulated. In order to evaluate the machinability by drilling under constant force feed, a machining schema based on the feed movement achieved by the test piece, from up to down, to the drilling tool found in a rotation movement, was identified. Some preliminary experiments were thought and materialized in order to test the applicability of this method of machinability evaluation. If the forces generated by the drilling process are high, some nonconventional machining processes based on the supplementary heating of the test piece in the zone affected by the machining process or on the use of mechanical vibration supplementary introduced in the machining zone could be taken into consideration and such nonconventional machining methods could be investigated in the future.

## 6. REFERENCES

1. El-Hoffy H., *Fundamentals of machining processes: conventional and non-conventional processes*, 1st ed., CRC press, (2006).
2. Hocheng, H., Tsai, H.-Y., *Advanced analysis of non-traditional machining*, Springer, (2013).
3. Karaguzel, U., Olgun, U., Uysal, E., Budak, E., Bakkal, M., Increasing tool life in machining of difficult-to-cut materials using nonconventional turning processes, *International Journal of Advanced Manufacturing Technologies*, Vol. 77, pp. 1993-2004, (2015).
4. Manole V., Slătineanu, L., Olaru, S.C., Iurea, P., Goncalves-Coelho, A., Results of an experimental research concerning the evaluation of machinability by drilling under constant feed force, *IManE 2015 Conference*, 21-22 May 2015, Iaşi, Romania, (2015).
5. Mascenik J., Gaspar S., Experimental assessment of roughness changes in the cutting surface and microhardness changes of the material S 355 J2 G3 after being cut by non-conventional technologies, *Advanced Materials Research* Vols. 314-316, pp. 1944-1947, (2011).
6. Picoş, C., *Machine manufacturing technology* (in Romanian), Editura Didactică şi Pedagogică, Bucharest, (1974).
7. Pradeep Kumar, G., Soundarrajan, M., Rajkumar, P., An experimental investigation of machinability of stainless steel 316 using brass electrodes, *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 4, Special Issue 6, May, pp. 640-649, (2015).
8. Rhoades, L. J., Applying nontraditional machining techniques for improved turbine engine designs, available at file:///C:/Users/TN5/Downloads/ V005T11A010-89-GT-267.pdf, accessed: 23.06.2015.
9. Sidda Reddy, D., Seshu Kumar, A., Sreenivasa Rao, M., Parametric optimization of abrasive water jet machining of Inconel 800H using Taguchi methodology, *Universal Journal of Mechanical Engineering*, Vol. 2, No. 5, pp. 158-162, (2014).