Comparative aspects about the studying methods of cast irons machinability, based on the tool wear

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Abstract. The paper presents some considerations of the authors, regarding the studying methods of the cast irons machinability, based on the tools wear on drilling operations. Are described the conditions in which the experimental researches were conducted, intended to offer an overview on drilling machinability of some cast irons categories. It is presented a comparison between long-term methods and short-term methods, for determining the optimal speed chipping of a grey cast iron with lamellar graphite, with average values of tensile strength. Are described: the research methodology, obtained results and conclusions drawn after the results analysis.

1. Introduction

Once with the industrialization and the appearance of machine tools, experts were aimed the more efficient processing of metals. It has reached so, that a series of researchers to be preoccupied by the development of some materials with appropriate properties to some industry needs, and others to discover and to develop processing methods for these new materials, in order to achieve the same goal: economic efficiency. It is noted that these concerns were maintained permanently until today due to the continuing development of various sectors of industries. The strong development of machine-building industry, automotive industry or of the aerospace equipment require the creation of new materials with outstanding physical, mechanical and chemical properties, but which are difficult to process by chip cutting. Knowledge the information of their machinability by chip cutting appears as an important issue for technologists. Thus, it would be possible establishing a priori the optimal working conditions, particularly in terms of manufacturing costs. Therefore, exist the anticipated establishing possibility of such costs.

Over the years researchers have been concerned about the creating of some machinability studying methods by chip cutting, for providing technologists concrete data about this technological property of materials. The experts were unanimously agreed that the machinability can be established based on three major criteria namely tool wears, the effort required at chipping and the roughness obtained after processing. Of course many subsequent researches showed that may be considered and other criteria that can give information on machinability: the chips shape, the temperature in the chipping area etc. [1, 2,7]. The studying methods of machinability, which watched the phenomena in their evolution, up to achieving a threshold limit, after which the chipping cannot be continued, have been named "long-term methods". Such research methods have the great advantage that can provide information as real about the ability of chipping of any material. The essential inconveniences of these methods categories are represented the high costs of materials, tools, energy, but also by large time consumed for the
experimental research. So, it was reached the necessity of creating more efficient methods, characterized by lower costs and minimal times namely "short-term methods". Of course was asked and still is and today asked: how close to the truth are the results obtained by such methods? As previously was mentioned, until now, in the attention of researchers have been various aspects that concern either the manner of holding the tests of machinability, or obtaining values of machinability characterizing parameters by chipping, specific to different categories of metallic and non-metallic materials.

Mocellini and his collaborators [4] chose to study the cast irons machinability with compacted graphite (CGI), compared with conventional grey cast irons, using the criteria of tool wear and the measurement of chipping efforts. Thus they concluded that cast iron called CGI, the structure which contained both lamellar graphite, with rounded ends, dispersed uniformly, and about 10% nodular graphite, has a tensile strength higher than ordinary cast iron with lamellar graphite, but also and a good chipping machinability. The drilling tests were focused on the study of tool wear, at which was considered the maximum wear ($V_{B_{\text{max}}}$) and the chipping forces, measured with a piezoelectric dynamometer.

In a paper published recently, Burke et al. [5] presented the results of a scientific investigation about the machinability of new cast irons types with different structures, obtained in induction furnaces, whose structure was checked by X-ray diffraction. They were carried out the drilling tests on nine cast irons types, keeping constant the processing time, speed work and the processing axial force. Doing so, it was noted that the machinability can be evaluated by the amount of material removed during chipping. It has been found that by measuring the weight loss of the sample after processing, can be estimated fairly well the machinability by chipping. Thus appears clear that these tests can be considered as being in the category of those of short-term.

In this paper, the authors aim to present some investigations conducted in the labs of "Gheorghe Asachi" Technical University of Iasi, to make a comparison between the results obtained by the two categories of methods outlined above. The research was carried out on samples made of grey cast iron with fine graphite lamellar, uniformly dispersed in metal base mass. The goal was to determine the machinability of grey cast iron based on tool wear, at drilling operations with the drill.

2. Experimental conditions

It is known that the tool wear phenomenon is due to some factors of different natures, after which the tool loses its ability to cut chips. In direct correlation with tool wear is the concept of "sustainability", which signifies the timeframe in which the tool is chipping in acceptable conditions.

This research was carried out on samples made of grey cast iron with fine graphite lamellar, uniformly dispersed in metal base mass. The shape of the samples was cylindrical having diameters of 120-150 mm and lengths ranging from 250-280 mm. Such a form allowed the obtaining of uniform structure and properties on the entire section of each moulded sample.

For the experiments it was used a boring mill with column with mechanical advances between 0.1 and 0.25 mm/rev and revolutions between 180 and 1.400 rpm. The characteristics of the samples are listed in table 1.

| Chemical composition (%) | | Chemical composition (%) |
|-------------------------|-----------------|-------------------------|
| C | 3.0÷3.2 | 1.6÷1.8 |
| Si | 0.7÷0.9 |
| Mn | 0.04÷0.06 |
| P | 0.1÷0.12 |
| S | 0.9÷1.0 |
| Cr | 3.0÷3.15 |
| Ni | 0.4÷0.5 |
| Mo | 0.1÷0.12 |
| V | Structure - predominantly pearlitic (65÷80%), with eutectic islands phosphorous disposed in network; The graphite - lamellar form with a length of 125÷250µm; has occupied an area of 8÷12%.

Table 1. Characteristics of samples used for the experiments.
In the long-term experimental research, the wear drills was appreciated based on the $VB_{\text{max}}$ size, of wear that occurs during chipping, on the main settlement of the drill face (figure 1). The measurement of the wear facet was carried out by moving the measuring wire from the ocular lens with the accuracy of 0.01 mm (figure 1 b).

For the wear appreciation was used a collapsible device, that allowed the convenient settlement of optical axis perpendicular to the principal cutting edge of the drill. A simplified representation of the device when is fitted to the drilling machine on that were conducted the experimental research is presented in figure 2.

Using the classical methodology for drawing the wear curves of the tools, it was possible to determine of the empirical relations for calculating chipping speed, after Taylor model, considering the limit wear: $VB_{\text{lim}} = 0.5$ mm, for speed steel tools, equation (1):

$$T^m = \frac{c}{v}$$

where $T$ is the tool durability, in minutes; $C$-constant; $v$- cutting speed in m/min.

![Figure 1. Sketch of wear measurement $VB_{\text{max}}$ of the drill.](image)

![Figure 2. The scheme of device used to measure the wear of drill at cast irons drilling.](image)

The work conditions and the experimental results obtained are shown in table 2. The mathematical processing of the results was performed using the least-squares method, aiming the determination of an empirical model power function type, equation (2):
\[ T = C \cdot v^b \]  

(2)

**Table 2.** The results obtained at drilling of some samples from two grey cast iron with lamellar fine graphite.

| Number of tests | 1   | 2   | 3   | 4   |
|-----------------|-----|-----|-----|-----|
| Chipping speed  | 7.91| 10.03| 12.71| 15.83|
| [m/min]         |     |     |     |     |
| Tool durability | 8.5 | 4.75| 1.66| 0.75|
| [min]           |     |     |     |     |
| The empirical relation &nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&n

Work conditions:
- Feeding rate 0.16 mm/rev;
- Diameter of helicoidal drill: 9 mm;
- Drills geometry: 2k=118°±1°, ψ=50°, ω=27°;
- Processed material: grey cast iron with fine lamellar graphite, uniformly distributed in the structure, with tensile strength 300[MPa], structure with 8÷12% graphite, and 65÷80% pearlite, with small islands of phosphorous eutectic, disposed in network.

By logarithm, a linear equation is obtained, that allows finding the C constant and the b exponent, whose values are in the durability and speed expressions, in table 2.

**Short-term experiments** were conducted using the [1, 2, 3] literature recommendations. During them, the speed increased in steps, in geometric progression, using the increasing revolution of drilling machine. For assessing the machinability, measurements were performed and were determined the time during which each sample produces a wear of the drill (VB).

In accordance with the recommendations of [1, 2, 3], the method imposing 7 + 1 machining, with increasing speeds in geometric progression, with the same tool, keeping constant the length of the hole machined at every speed step.

After the performing of those eight experiments, with different speeds and increasing, is recorded machining time \( \sigma_i \) and the wear VB, obtained after each after each machining. Although the method has been recommended for turning operations [3], the authors applied it to drilling operations with the drill, keeping constant the length (depth) of the hole machined with the drill.

The specialized literature [3] shows that the wear on the main settlement of the drills VB can record a linear evolution, in relation with the time and the chipping speed, following a relation as (3):

\[ VB = k \cdot \sigma \cdot v^x \]  

(3)

where \( k \) is a constant, \( \sigma \)-chipping time, \( v \)-cutting speed, \( x \)-exponent

From the analysis of relation (3) it can be deduced that the limit value of wear (VB\(_{\text{lim}}\)) occurs when working time is equal with the tool durability (\( \sigma=T \)). Based on this reasoning, it can replace in equation (3), the \( T \) size, extracted from equation (1), which leads to:

\[ VB_{\text{lim}} = k \cdot T \cdot v^x \]  

(4)

As machining at each gear occurs in a \( \sigma_i \) time and produces a VB, wear, can determine the fraction of tool total wear, which remove the tool from service, after those 8 experiments:
Based on the recommendations from [3], the obtained results from the machining with speeds having stepped sizes can be used to draw a graph which represent the equation of a line in simple logarithmic coordinates, as:

\[ Y = b \cdot S + a \]  

(6)

where \( b \) is the slope of achieved graphic, \( a \) - is the point ordinate in which take place the line intersection with the ordinate axis and \( S \) - is the number of gears used to reach the limit of wear.

The a and b sizes can be used to determine the \( m \) exponent and the \( C \) constant from equation (1):

\[
m = \frac{\lg q}{b + \lg q} \quad \text{and} \quad C = \frac{v_0 \sigma_0^m}{10^m} \cdot \left( \frac{1}{q^{\frac{1}{m}}} - 1 \right)
\]

(7)

where \( q \) - is the geometric progression ration of chipping speed (for drilling machine used at experiments: \( r=1.26 \)); \( v_0 \) - initial speed, obtained in the first gear of drilling machine, m/min, \( \sigma_0 \) - machining time of the first hole (with the first gear), min.

**Figure 3.** Chart for determining the \( a \) and \( b \) constants.

The experimental conditions and namely the used speeds, as the wear values obtained of each machining, are shown in table 3.

| Number of gear | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| The speed at each step, m/min | 5.08 | 6.41 | 8.07 | 10.18 | 12.82 | 16.16 | 20.3 | 25.66 |
| Wear VB, mm    | 0.2  | 0.25 | 0.28 | 0.33 | 0.34 | 0.45 | 0.5  | -   |

Percentage wear,

\[
U_{\%} = \frac{VB_i}{VB_{lim}}
\]

|               | 0.4 | 0.5 | 0.56 | 0.66 | 0.68 | 0.90 | 1.0  | -   |

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\[ U_{\%} = \frac{VB_i}{VB_{lim}} = \frac{\sigma_i}{T} \]  

(5)
Using the data from table 3 was possible to determine the values of the \( C \) constant and of \( m \) exponent in equation (1), for the short-term method, applied to the same material, with the same tool, on the same drilling machine and implicitly the relations of \( T \) durability and \( v \) speed:

\[
T = \frac{180.41}{v^{1.68}} \text{[min]} \tag{8}
\]

\[
v = \frac{22.03}{T^{0.59}} \text{[m/min]} \tag{9}
\]

Introducing in the \( T \) durability relations, obtained after experimental data processing, equations (1) and (8), from table, can be drawn \( T-V \) curves for both determining procedures of machining by chipping with the drill of cast iron (figure 4).

**Table 4.** Synthetic presentation of the obtained results at the use of long and short-term methods for determining the machinability of grey cast iron by drilling operations with a drill.

| Chipping speed at each step [m/min] | 5.08 | 6.41 | 8.07 | 10.18 | 12.82 | 16.16 | 20.3 |
|-----------------------------------|------|------|------|-------|-------|-------|------|
| \( T \) Durability \( \text{long-term method} \) \( T = \frac{1724.182}{v^{3.6}} \text{[min]} \) | 49.74 | 21.47 | 9.37 | 4.06 | 1.77 | 0.77 | 0.33 |
| \( T \) Durability \( \text{short-term method} \) \( T = \frac{180.41}{v^{1.68}} \text{[min]} \) | 11.76 | 7.95 | 5.4 | 4.4 | 2.28 | 1.68 | 1.14 |

The examination of the relations included in table 4 highlights that the chipping speed \( v \) exert a stronger influence on \( T \) durability in case of long-term method, given the higher value of attached exponent to \( v \) size, in relation with the value of the same exponent in the corresponding relation of short-term method. A suggestive illustration of this situation is the graphical representation of figure 4.

**Figure 4.** The influence of chipping speed on drills durability at grey cast irons with uniform lamellar graphite dispersed in metal base mass.
3. Conclusions
The analysis of data from Table 4 and the graphs from figure 4 shows that the short-term method, of grey cast iron pieces machinability determining, with a tensile strength of 300-325 MPa, with uniform distributed graphite in metal base mass, it can be successfully used in some areas of work speed (at least 9 m/min). Over these values of chipping speed, as shown in figure 4 are overlaps of the two curves.

Also, it has been confirmed that the research method of machinability, by increasing the working speed in geometric progression, usually, recommended for turning operations can be successfully applied for drilling operations.

In the future, the authors plan to continue the research by extending the investigations in the same direction, but for more types of cast irons, of high strength, to observe if the short-term methods are valid and in these situations.

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