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Study of the Machinability of AISI P20 and AISI H13 1010 by Drilling Test with Constant Axial Force at the Drill Tip

Estudio de la maquinabilidad del acero AISI P20 y AISI H13 por ensayo de taladrado con fuerza axial constante en el punta de la broca

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AISI P20,
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Drilling

ABSTRACT

Machinability in general terms, is the ease with which a material can be machined through chip removal, according to a set of cutting conditions. It is necessary to have a quick methodology for the comparison of machinability between materials in order to choose, which of them is the optimum according to the working conditions given by the designer. To carry out a comparative study of the machinability of AISI P20 and AISI H13 Mold Steels by means of the drilling test with constant axial force at the tip of the drill bit. In order to perform machinability tests, a drilling machine was adapted to perform the machinability tests between two steels widely used in the construction of machine parts and components, AISI P20 and AISI H13. In this type of test, little time is invested in machining and little material is used, obtaining the optimum cutting conditions and machinability values.

Palabras clave:

Maquinabilidad, Ensayo acelerado,
AISI P20,
AISI H13,
Taladrado

RESUMEN

La maquinabilidad en términos generales, es la facilidad con la que un material puede ser mecanizado por arranque de viruta, según un conjunto de condiciones de corte. Es necesario disponer de una metodología rápida para la comparación de la maquinabilidad entre materiales con el fin de elegir, cuál de ellos es el óptimo según las condiciones de trabajo dadas por el diseñador. Realizar un estudio comparativo de la maquinabilidad de los aceros moldeados AISI P20 y AISI H13 mediante el ensayo de taladrado con fuerza axial constante en la punta de la broca. Para realizar los ensayos de maquinabilidad, se adaptó una máquina de taladrar para realizar los ensayos de maquinabilidad entre dos aceros muy utilizados en la construcción de piezas y componentes de maquinaria, el AISI P20 y el AISI H13. En este tipo de pruebas se invierte poco tiempo en el mecanizado y se utiliza poco material, obteniendo las condiciones óptimas de corte y los valores de maquinabilidad.

Introduction

The term "machinability" refers to the "relative ease with which a given material (or group of materials) can be machined" using the appropriate tools and cutting parameters. Several factors affect the machinability of materials; among them are the cutting conditions (cutting speed, feed rate, depth of cut, operation and lubrication), the tool (material and coating, geometry), and the material (composition hardness and machining conditions [1, 2]. A material that is easy to machine will have a direct effect on machining costs, cycle time and productivity, and thus on the competitiveness of a company [3]. In addition to the ease of stock removal, the quality of the resulting surface and the life of the cutting tool are of primary importance in the concept of machinability [4]. In spite of the great importance that the machinability of materials has in the industry when carrying out mass production processes, few studies at an academic level are developed, due to the difficulty of performing experimental tests in normal industrial production environments [5]. There are a wide variety of parameters that can be used as a basis for machinability tests, chip

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temperature, chip thickness, power consumed by the machine when machining, tool wear, surface finish, among others [6]. Most of these require large amounts of tests and material to be tested, making the cost of the test high, as well as its difficulty to perform, mainly due to the complexity in the control of the variables, for example, a minimum variation in the cutting angle of a burin, could represent a significant change in the size of the chip during a turning process, making lose the fidelity of the test results taking as reference this fragment of material. [7]. Likewise, if a test is carried out on the basis of tool wear, a batch of materials would have to be tested by performing a machining process in which the wear produced at the cutting edge of the tool is very sharp. So much so that it can no longer remove material, a process that in addition to requiring large quantities of material to perform the tests, can take days to produce such wear on the tip of the tool. [8]. To determine the machinability of materials there are many tests, among the most used we have the tool life time test, the surface finish test, the cutting force test, the power consumption test, the cutting temperature test and the chip shape test. Machinability grade is a number assigned to indicate the ease or difficulty of machining a material. This concept was introduced in the early 20th century, when the market was dominated by high-speed steels. The cutting tool life obtained when turning B1112 steel with a high-speed steel tool at 55 m/min was assigned 100%. Machinability grades were assigned to the other materials based on the relative tool life when machined under similar conditions [8]. Several machines can be used to perform a machinability test, among these are the milling machine, honing machine, drilling machine, lathe, among others. To choose the machine for the test, economic and technical aspects should be analyzed, depending on the conditions to perform the machinability test, one machine will be better than another. With the passage of time and the evolution of technology, tests other than those mentioned above have been developed to determine whether the materials have a good behavior when machined. These tests can be divided into two types, "normal" and "accelerated". In both tests, the aim is to determine the machinability of the material according to the degradation suffered by the cutting tool after many tests [9]. The "normal" tests impose a work rate on the tool, and it is machined until the tool becomes unusable. The time taken to render the tool unusable is computed, and this time indicates the degree of machinability of the material. Later, "accelerated" tests arose as a result of the need for time and material required to perform a "normal" test [10]. The "accelerated" tests are based on the fact that the life of the tool is determined by the manufacturer under certain conditions of use, and from the coefficients of the Taylor equation, it is possible to extrapolate the speed with which the test has to be carried out so that it lasts a certain time. Therefore, a sufficiently high speed is seeking to achieve a test in a relatively short time. This is when the concept of accelerated testing appeared [11-12]. In order to reduce the time and material used in characterization tests, a test is sought that allows the machinability of materials to be characterized quickly and reliably. The machinability test based on tool wear proposed by Costa [13], in which a tool rotation speed and the force exerted by the tool on the material are fixed, highlights the importance of studying cutting tool wear as a fundamental aspect in machining, because the factors that influence this method can be controlled more easily than in the other existing tests and the machinability value can be quantified. It is a novel, fast and easy to apply test, which makes it suitable for use in workshops where it is necessary to compare or characterize in a fast and reliable way the machining properties of a material. In order to carry out the test proposed by Costa, it is necessary to have a machine with the characteristics that allow it. The most important characteristics that the machine must fulfill are:

1. To be able to know and control the force exerted by the tool on the surface of the material to be tested.

2. Do not force the advance of the tool.

3. To be able to control the speed at which the tool rotates.

4. To be able to control the time that elapses from the moment the tool starts to drill the material to be tested until it has already made the hole.

One of the machines that allows to fulfill these characteristics is the manual drilling machine, because it allows the controlled application of force. In the process of performing the drilling test, holes are drilled with constant feed and to know the wear of the tool, the parameter of the axial force applied and the torque applied to the drill is recorded.

Materials and Methods

Modification and set-up of machine for tests.

Initially, in order to advance in the implementation of this test, we proceeded to the adaptation of a drilling machine, which would allow the execution of the type of test proposed [14].

In a machinability test for constant load drilling, two main variables are involved: the cutting speed, which depends on the rotational speed of the drill, and the feed rate, which depends on the force applied to the tip of the drill. Therefore, in this type of test, cutting speed (m/min) and load (N) conditions are set, which will be defined depending on the diameter of the drill bit and the values that are experimentally used to machine the tested material or similar materials.

The test procedure consists of measuring the time it takes for the drill bit to drill a hole in the material under study, guaranteeing fixed conditions of drill rotation speed and drill bit tip force. To guarantee the constant force at the tip of the drill bit, a scheme is proposed in which the head or main shaft of the drill chuck is released, but in turn attached to a pulley, this pulley allows by means of a tray tied to a rope to induce a load, by means of a mass placed at the end of the rope. This assembly allows to guarantee the principle of the proposed method, to maintain a constant axial force on the tip of the drill, while the machining, in this case drilling, is carried out.

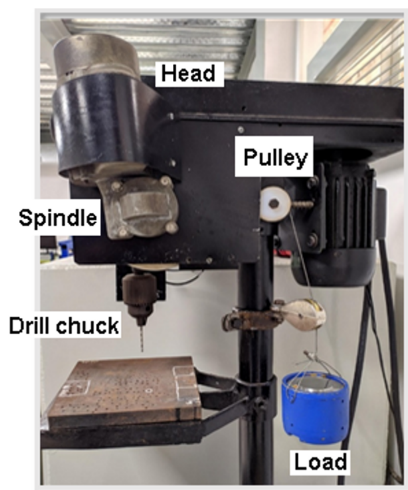

Figure 1. Drilling machine test. [14]

In this test, a short machining time and a small amount of material are used to obtain the optimum cutting conditions and machinability values. Under the criteria of productivity and machining quality, the relative machinability is compared between materials.

An investigation about steels for molds is carried out in this comparative study of machinability, the accelerated test proposed here was carried out between two steels widely used in the manufacture of plastic injection molds, the pre-hardened steel for molds AISI P20 and a hardened steel for molds AISI H13 [15]. AISI P20 pre-hardened steel is a type of steel that is frequently used in large molds, molds with large production series, molds with high resistance to wear and corrosion, plates that support high compressive strength. This type of steel has as design conditions to have a hardness between 270-350 Brinell, because it is treated in hardening and tempering. Suitable for a wide range of injection, blowing and extrusion molds [16].

The AISI P20 steel offers good machinability, homogeneity, excellent polishability and uniform hardness. Composed of nickel, chromium, molybdenum, carbon, silicon, manganese and a low sulfur content, its advantages include the fact that it does not require hardening, thus reducing the cost of this treatment, and can be nitrided to increase its wear resistance.

The AISI H13 hardened steel is a type of steel frequently used in molds for large production runs, to resist the abrasion of some materials, for hot work, with good wear resistance, good polishing capacity and can withstand high injection pressures [17]. Normally, roughing, stress relieving, finishing by machining, hardening and tempering operations are performed to the required hardness. AISI H13 steel is a steel composed of carbon, silicon, manganese and alloyed with chromium, molybdenum and vanadium. It offers good resistance to thermal shock and thermal fatigue, good mechanical strength at high temperatures, toughness and good ductility in all directions, dimensional stability during hardening.

In the execution of the test, holes of known and constant depth are made, never more than 5 times the diameter of the drill bit to avoid making very deep holes, and for each one of them the time spent in making it is recorded. It is recommended that the machined holes are not through holes, thus avoiding the over wear that appears when the hole is opened [18]. During the test, as the holes are drilled, the drill bit wears, therefore, the drilling time increases. Then, the drilling operation is repeated until the wear of the drill bit is so great that, with the load applied, the tip cannot penetrate the material and, consequently, is not able to advance.

This same test is repeated for the material with which the machinability is to be compared. With the two tests performed, the machinability of each material is obtained, which is a function of the number of holes machined and the time taken to perform them. The application of this comparison method makes it possible to define which material has better machinability for given cutting speed and load conditions. Furthermore, depending on the cutting conditions used, tool wear may be slow so that a large number of holes would have to be drilled to complete the test, so a representative number of holes will be established for the test, thus saving time and test material.

Rapid test and parameter used to assess machinability

The accelerated test is defined as an application method to compare the machinability of both materials, which will be related to tool life and machining quality, given by the cutting conditions used in each test to be tested [19-20].

In this methodology, drilling is performed with constant cutting speed and constant axial load on the material, so that in each test the combinations of force and speed are different, so that for each speed we will use a new drill bit and a maximum load will be applied on it. According to this cutting configuration, a certain number of holes are machined, then, the test is repeated with the same previous speed, the only difference of this new test is that the load is lower, the same number of holes are drilled as in the first test cycle performed, and these tests are repeated until all possible cutting conditions are executed.

The greater the number of holes drilled in each test, the more representative it will be under each speed and axial load configuration. Thus, for materials of good machinability, it is recommended to use the same drill in the different tests for each cutting speed (i.e., varying only the load value) and to perform between 20 and 50 holes in each test. On the other hand, if the machinability of the material to be tested is poor, it is recommended to change the drill bit in each test and, even then, the tool wear may still be very high, so the number of holes can be reduced.

From this test, the drilling times and the number of holes drilled for each of the cutting conditions used are obtained. With this information the following parameters are calculated for each combination of axial load and cutting speed.

1. Average feed rate, a_m [mm / rev]:

$$a_m = \frac{60 * Z * h}{Z * n * T_m} = \frac{60 * h}{n * T_m} \qquad \text{[Eq. 1]}$$

Where, T_m [s] is the average bore time for each combination of load and speed, Z is the number of holes in each combination, h [mm] is the depth of the machined holes and n [rpm] is the rotational speed of the drill bit.

2. Length drilled per unit time, L_m [mm/min]:

$$L_m = \frac{60 * Z * h}{Z * T_m} = \frac{60 * h}{T_m} \qquad \text{[Eq. 2]}$$

3. Percentage of the length of the hole length with respect to the average value of the entire length, *%L*:

$$\%L_{ij} = 100 * \frac{a_{mij}}{\frac{\sum_{j=1}^{k} a_{mij}}{k}} \qquad \text{[Eq. 3]}$$

Where, *ij* = combination of cutting speed "*i*" and load "*j*", *k* = number of different loads applied at each speed "*i*"

4. Stability ***E*** (*%*). Parameter that relates the dispersion of the drilling time values with respect to the average time of each combination of axial force and drill bit rotation speed:

$$E_{ij} = 100 * (1 - \frac{4 * \sigma_{ij}}{T_{mij}}) \qquad \text{[Eq. 4]}$$

Where, *σij* is the standard deviation of the drilling times, and Tmij is the average drilling time

Machining quality is quantified by stability. High stability means uniform drilling times, i.e. regular machining, ideal for applications where surface finish is important. Conversely, low stability indicates large fluctuations in machining times, which is representative for operations where finish is not influential. A parameter is now established in order to be able to evaluate machinability in terms of quality and productivity:

$$P_{Cij} = \propto * E_{ij} + (1 - \propto) * \%L_{ij} \qquad \text{[Eq. 5]}$$

To calculate this value, alpha (*α*) values are set between 0 and 1, with a step of 0.25, in order to obtain values according to productivity (machined length L predominates) and according to finishing quality (stability E is more important).

Assessment of machinability

The machinability of each material is defined as the product between the average feed rate (*am*) and the cutting speed (*Vc*), for each of the combinations of force and speed, this value is known as the material machinability index (*Ir)* choosing which cutting condition is the best suited to the process, either looking for a high quality rate or productivity. The next step consists of plotting the combined parameter for each material and for each alpha level (*α*) considered, from them we obtain the cutting speed (*Vc*) and the average feed rate (*am*) that give us a maximum combined parameter. Finally, in order to compare the machinability of the materials, the results obtained for each of the materials are tabulated and the "Relative Machinability Coefficient" parameter Cmr is calculated as relative machinability for each value of α.

$$Cmr = \frac{a_{m1} \cdot V_{c1}(material\ 1)}{a_{m2} \cdot V_{c2}(material\ 2)} \qquad \text{[Eq. 6]}$$

Results and Discussions

In this test not used any type of cutting fluid, a drill to Ø 9/64" (3.57mm) is used, for each cutting speed and axial load configuration, we will drill holes with a depth of 10 mm. During the test, the time elapsed from the start of the machine until the bit holder reaches the end position sensor is recorded. Once the number of holes required for the test has been drilled, the drill bit returns to the initial position. With the recorded times, the average feed rate, drilled length, stability, and machinability index are calculated. Figure 2 shows the testing machine and the performance of each test.

Figure 2. Machinability test.

The drilling times obtained for AISI P20 steel and for AISI H13 steel are shown below. Table I.

Table I. Drilling times obtained for AISI P20 and H13 steel, drill bit of 9/16" and 1640 rev.

	AISI P20		AISI H13	
Load	**3.5 Kg**	**3.0 Kg**	**3.5 Kg**	**3.0 Kg**
Hole	Time	Time	Time	Time
1	15,31	24,50	21,56	16,79
2	14,72	23,72	19,57	16,09
3	15,29	23,28	19,26	14,65
4	15,00	22,91	16,56	14,51
5	15,21	23,07	15,42	14,13
6	14,67	23,10	18,20	13,95
7	16,02	22,63	15,90	13,97
8	15,76	22,51	18,46	13,92
9	16,34	22,37	17,22	13,75
10	16,71	22,31	14,74	13,80
11	16,75	23,48	15,79	13,58
12	16,64	23,02	16,23	13,94
13	17,10	24,18	16,36	13,93
14	17,55	23,67	16,24	15,90
15	17,28	24,01	16,18	14,56
16	16,43	24,96	15,89	16,14
17	16,93	24,51	16,95	21,77
18	16,74	25,35	15,88	20,32
19	16,66	26,01	16,21	21,56
20		25,91	16,49	

By means of the data obtained, the drilling time, Figure 3, was plotted for AISI P20 and AISI H13 steel, in order to compare the drilling time of each hole vs. the load applied on the drill bit.

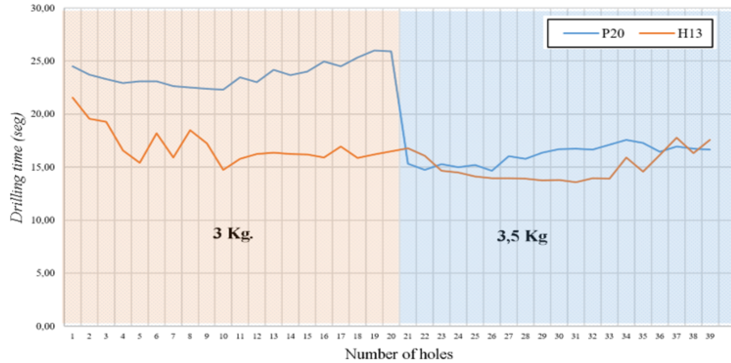

Figure 3. Drilling times of AISI P20 and H13 steels for constant loads of 3.0 kg and 3.5 kg.

In the Figure 3 shows a similar behavior for the materials, as the drill holes are drilled, the cutting edge of the drill bit wears, which causes the drilling time to increase as more holes are drilled. The load applied to the drill bit is inversely proportional to the drilling time, the higher the load applied the shorter the drilling time.

On the basis of the data obtained in the test, the parameters are calculated to find the relative machinability index of the material. The average feed rate (Eq. 1), average drilling time (Tm), length drilled per unit time (Eq. 2), percentage drilled parameter (Eq. 3) are also calculated. The machinability is assess which stability parameter (Eq. 4).

Table II. Parameters for assess machinability in AISI P20 and AISI H13 steels.

	AISI P20, *Vc* 1640 rpm		AISI H13, *Vc* 1640 rpm	
	3 kg	**3.5 kg**	**3 kg**	**3.5 kg**
Tm	23,775	16,164	16,956	15,645
am	0,0153	0,023	0,022	0,023
σ	1,132	0,896	1,657	2,663
Lm	25,236	37,120	35,387	38,350
%L	80,942	119,058	95,981	104,019
E	80,945	77,838	60,903	31,904

In the Table II shows that for each of the calculated parameters, the highest stability between both materials was achieved when the applied load was 3kg, so it was decided to use that configuration for the next step.

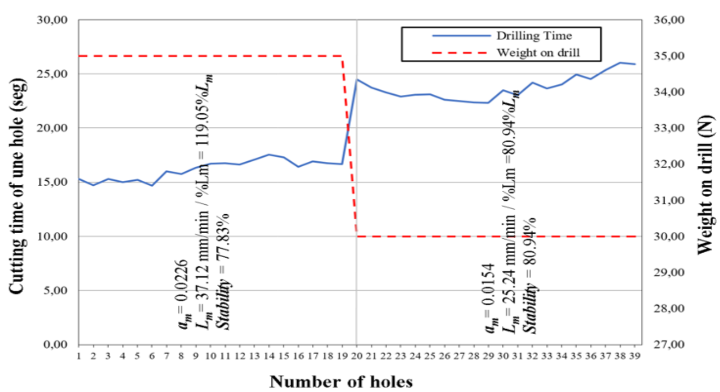

Figure 4. Cutting time for a P20 steel Cutting speed use Vc = 16.36 m/min.

In the Figure 4 and 5 show how P20 steel shows better stability during machining with respect to H13 steel, especially when the load on the drill bit is decreased.

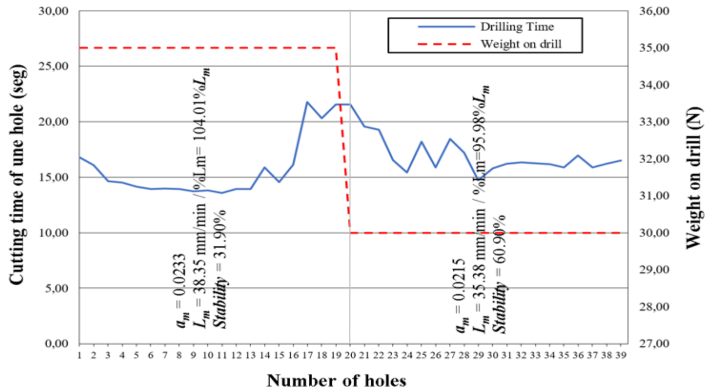

Figure 5. Cutting time for a H13 steel Cutting speed use Vc = 16.36 m/min.

A summary table (Table III) is made with the data obtained for each of the materials and the Relative Machinability Coefficient Cmr is calculated with equation 6, as relative machinability for each α value.

Table III. Calculation of the combined parameter for each α level.

α	AISI P20					AISI H13					Cmr
	Vc [m/min]	Load [N]	a_m [mm/rev]	Pc	a_m*Vc	Vc [m/min]	Load [N]	a_m [mm/rev]	Pc	a_m*Vc	
1.00	16,36	30	0,0154	80,95	0,252	16,36	30	0,0216	60,90	0,353	1.4
0.75	16,36	30	0,0154	80,94	0,252	16,36	30	0,0216	69,67	0,353	1.4
0.50	16,36	30	0,0154	80,94	0,252	16,36	30	0,0216	78,44	0,353	1.4
0.25	16,36	30	0,0154	80,94	0,252	16,36	30	0,0216	87,21	0,353	1.4
0.00	16,36	30	0,0154	80,94	0,252	16,36	30	0,0216	95,98	0,353	1.4

Conclusions

In the data obtained in the test carried out for AISI P20 steel, it is observed that as the number of holes increases, the drilling time in the material also increases, which indicates that the tool is wearing out each time it is drilling a new hole. Also, the applied load is inversely proportional to the drilling time, the higher the axial load applied on the material, the shorter the drilling time. As shown in the results, AISI P20 steel presents drilling times higher than those of AISI H13, however, it presents stability values 24% higher than AISI H13, indicating better behavior at the time of machining, for P20 steel when testing with a load of 3, 5 kg, it is observed the formation of continuous and long chips when it touches the surface when reaching from the middle to the lower dead point, then it was decreasing in length and being discontinuous, unlike the H13 in which discontinuous chips were presented. When the 3kg load is exerted on the P20 steel, from hole 1 to 3 the chip was initially a little more continuous, but when it reached the middle of the borehole it became discontinuous and short, from hole 3 to 14 the chip length is small from the beginning to the end of the borehole and after hole 15 the chip formation is almost minute and discontinuous, unlike H13 in which discontinuous chips were present. This also indicates that P20 steel is more suitable for machining where surface finish rather than productivity predominates than H13 steel. However, in most industries the most representative value is productivity, so the calculation of the relative machinability index (Cmr), resulting in 1.4 (taking AISI P20 steel as a reference), which means that, for the same cutting speed, AISI H13 steel is 40% faster to machine, or, in other words, more productive. Although the AISI H13 steel has carbon (C), silicon (Si), molybdenum (Mo), chromium (Cr) and vanadium (V) content, it could be deduced that the drilling time would last longer in this material than in the AISI P20 steel since it has better properties, in the AISI P20 steel when it is heat treated in quenching and tempering this improves its physical properties making that in the drilling tests it has a longer drilling duration.

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