Machinability Study of an aluminum-copper alloy

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ABSTRACT

Machinability of materials is one of the factors that make us wonder what tools to use and what material is best suited for a particular cutting tool and which process is more efficient in the production of a component. In the case of parts for the aerospace industry, manufacturing processes assume greater importance due to the extreme demands on reliability and quality.

Although today composites are used in a high percentage of aircraft components, they suffer from the problem of recycling. By contrast, the aluminum alloys fulfill the environmental requirements, besides being lightweight.

The machinability of steels has been extensively studied, but this has not happened in the case of aluminum alloys. Thus, this paper presents a methodology for characterizing aluminum alloys from the point of view of its machinability, enabling senior students to make their final projects, comparing different alloys for aeronautical use. To obtain the characteristics in each alloy, students must handle a wide range of equipment: durometers, scales, SEM microscopy, optical microscopy, lathe machine, etc, increasing their education and training.

Keywords: machinability, methodology, aluminum, tools, wear, lathe.

INTRODUCTION

During the years of a career, most students are able to get a lot of knowledge that came from all of work developed by them. In that case, most of them need to understand why they learn this theoretical knowledge and how execute it. Therefore, activities are required to encourage eagerness and willingness of the student. An example of this practice is students' final degree project.

The final engineering project is the goal of any engineer who is in his or her last year of career. Any project must keep students on a continuous learning which improves their abilities and/or competences. In the end, improving students' attitudes through the realization of a final engineering project involves an improvement of general activities performed at university such as laboratory techniques or knowledge integration tasks.

IMPROVING RESEARCHING COMMITMENT

At the university, research techniques may enrich students' background and may improve their working possibilities. Companies often do not know anything about the student's training. Human resources just find out a small part of the experience which is achieved by learners. If research commitment was developed among student and university, there would be a direct link between university and enterprise that would allow companies to hire professional people with a better training.

On the other hand, professors and university staff must maintain the necessary commitment to meet challenges in the best possible way. Even more when students rely on solutions provided by them.

In consequence, a machinability study could take place into the university in order that pupils are conscious of the research benefits. This work allows them to handle a lot of equipment such as SEM (Scanning Electron Microscope), a lathe, weighing scales, and durometers among others. In addition, this scheme makes easier the recently graduates inclusion to the labor market because they can learn something else about the know-how of companies.

In conclusion, it is about to improve the training lack through the use of projects that have a high contents on practice activities.

Repercussions about the machinability study in the industry

Machinability is defined as the relative ease or difficulty of removing metal in transforming a raw material into a finished product [1]. This factor encompasses a great number of subjects and engineering fields to the point that this value can enhance economic added value of a product. Materials science or manufacturing are some examples of those fields but other subjects like physics, material strength, and chemistry are involved too.

The fact is that this type of study has a great impact in the economy of a company, since the determination of this factor penalizes or improves the manufacturing time. The amount of time that a company spends on making new products is crucial to fulfill the requirements of the market. If an organization does not manage its manufacturing time in an efficient form, it could be detrimental for inventories and the deadlines compliance and, as a result of this, customers' distrust is generated.

In the aeronautical field, for instance, the production time must fit the strict deadlines which customers impose on manufacturers. Furthermore, difficulties based on aerodynamics are added, since a particular component of an aircraft has to be suitable for a functional behavior and must fit in somewhere with stringent tolerances. At first sight, it could seem laborious coming to an agreement about this, nevertheless the reality is that organizations invest much money to sort out these obstacles.

Hence, building a methodology that comprehends all of these engineering areas is a hard task which depends on the student's ability to get along on these related fields. In the same way, designing a plan that provides the way to work firmly is essential to achieve the objective.

Given these points, it seems reasonable setting a plan up which helps trainees throughout their last year of career to take suitable solutions to confront the next labor years.

MACHINABILITY METHODS

The experience has confirmed which differences exists when it is time to mechanize a wide range of materials due to properties or features that show when are processed. Therefore, measuring and evaluating these differences is required. At this point it comes into play the machinability which has mentioned in previous paragraphs.

Most tasks associated with the study have to do with mentioned areas above among which are measure techniques with measuring tools, empirical procedures, and use of software.

The method followed by this paper follows the machinability standars. Actually, there are several methods to accomplish a machinability factor, but generally include the following [2]:

- Tool life or wear tests
- Surface finish tests
- Cutting force tests
- Power consumption tests
- Cutting temperature tests

Tool life is generally considered to be the amount of time the tool produces parts with acceptable finish and/or tolerance while not showing sufficient wear to be danger of catastrophic failure [2].

In the case of this study, the tool life or wear test was chosen in order to obtain a specific machinability factor. In order to determine a machinability rating based on tool wear, tests are performed at one speed on a range of materials, using one type of cutting tool material and one geometry. Thus, a certain amount of tool wear is found later will be compared with other materials to specify a machinability rating. For instance, if there are a few materials such as three different aluminium alloys and, afterwards, tests are conducted on these samples, it is possible to evaluate different tool wears on those cutting tools, allowing the determination of a machinability rate.

Also, it was investigated the surface finish which contributes to this work doing more real the performed study, since the analysis of the roughness enables to know if the procedure fits to the concluded mechanical process.

REQUIRED RESOURCES TO DEVELOP A MACHINABILITY STUDY

In every cutting process is imperative using tools which make possible the last objective, that is, applying many operations in a broad range of samples and obtaining the best functional use of carried products out. In particular, this sort of research needs, above all, measuring devices and all type of machinery. By the same token, having appropriate installations to perform all of these actions is fundamental as well.

However, many times the utilization of the best devices is almost impossible. Consequently, in this paper are suggested some needed devices to reach the aim.

For the purpose of accomplishing this investigation is an indispensable requisite having the minimum following tools:

- A lathe which allows performing mechanical processes
- Workpieces of several materials, in this case, aluminum alloys
- At least, one cutting tool with one defined geometry
- High precision weighing scales
- Durometers that enable Vickers and Rockwell tests
- Optical Microscope and Scanning Electron Microscope and its related software
- Cleaning tools to prepare samples for its insertion in microscopes, i.e., ultrasonic cleaner or similar
- A spreadsheet software to arrange acquired data from gathering measures
- A chronometer which allows taking times
- A roughness tester

In order to increase the accuracy of outcomes, it would be possible the use of next equipment[I]:

- Power consumption measurement tool
- Non-contact temperature sensors or temperature probes
- A cutting force dynamometer

Study constraints

Before making tests, professors and students have to know that it may be limitations at time to proceed to processes and mechanical procedures. These restrictions may be derived from inadequate and defective tools or from choosing inappropriate variables. That is to say, used resources such as a machine, a tool and so on must be checked to avoid bad outcomes in the investigation.

[I] For each case it is needed a software to take data from all of these tools

METHODOLOGY AND EXPERIMENTAL TECHNIQUES

It is important to determine how has been achieved a methodology to implement a research study in the student development. Accordingly, the steps were established to reach the first objective of this dissertation; obtaining a machinability factor for this material.

At first, it was required setting actions out in a closed field. Consequently, cutting variables were studied to ensure reliability of results. These values are evaluated as a feed rate, depth of cutting, and cutting speed so that many factors impinge on these decisions because all of the dependent variables are influenced by them. Proper selection of variables that have been selected; that is, the total amount of material to be removed, the workpiece and tool materials, and the machining process or processes [3]. These chosen factors are essentials when it comes time to make tests.

Work schedule

At this point, the steps of this research will be shown in the following arguments in order to establish an action plan so that the realization of this experiment can be carried out in the better conditions as well.

For this purpose, a workpiece material of aluminum-copper alloy was chosen to perform these tests. The used alloy was 2030 whose designation is defined by Aluminum Association. This material has a few remarkable mechanical properties such as light weight, high tensile strength and, corrosion resistance. Thus, measures on the material were taken before making the experiment for checking if material properties could previously be modified. Measures already said have been achieved as a weight estimation using a weighing scale what involve the density of material can be determined. Furthermore, hardness assays were executed in such way which results in values between 62 and 65 HRB.

To clarify the previous section, the aluminum alloy is preferred in this case study by its extensive use in the aeronautical domain. Aluminum alloys exhibit exceptional attributes, what is required when a device or a machine has to fly, above everything when it deals with light weight applications. Other alloys could be appropriate to other investigations.

For this study, two cutting tools were chosen. Then it was necessary assessing each cutting tool using Scanning Electron Microscopy (SEM). The tools undergo changes in its composition when they are subjected to mechanical processes. As a result of these treatments, cutting tools may experiment a significant wear. Therefore, it is required measuring this wear and how this changes the process. Actually, in most cases, processes have a great impact on the wear of the tool, however the tests are erroneous input variables do not provide the expected wear. Following this trial, the cutting tools had to be cleaned before its insertion into the SEM because dust particles or strange elements could delay achieved outcomes. For this purpose, cleaning cutting tools using ultrasonic cleaner was made through the utilization of acetone.

Regarding to the preceding paragraph, each cutting tool has six cutting edges which were named to avoid misunderstandings. These edges were numbered as following: the first digit expresses the number of the tool (1 or 2), the letter (a or b) defines the cutting tool face and, the third digit typifies the edges by each face (1, 2 or 3).

In the end, 24 tests were carried out, so that two tests were performed by each cutting tool and, by each cutting condition. For these analyses it was required designing a terminology which will allow handling data in the better successful way. Nomenclature it is formed through the designation of each operation. Every assay was constituted by eight conditions (i1, i2… i8) with i = A, B, and, C. To illustrate the previous argument, it is shown a table to clarify the issue.

Test	Edge	$N_{Theorical}$ (rpm)	a_p (mm)	f (mm/rev)	$Speed_{ii}$ (m/min)
A1	1a1	400	3	0.1	62.83
A2	1a1	400	3	0.1	62.83
A3	2a1	400	3	0.18	62.83
A4	2a1	400	3	0.18	62.83
A5	1a2	600	3	0.1	94.25
A6	1a2	600	3	0.1	94.25
A7	2a2	600	3	0.18	94.25
A8	2a2	600	3	0.18	94.25

Table 1. Ideal values expected in the A test and cutting tool terminology

On the subject of mechanical operations, estimating revolutions per minute is an exercise to do before processes have been done. Hence, a preliminary evaluation of the lathe behavior must be performed in order to acquire the optimum procedure. Therefore, two constant cutting speeds of about 63 m/min and 92 m/min were selected in order to make mechanical tests. These speeds were confirmed by lathe performance. For tests, revolutions were selected as following:

- A: 400 and 600 rpm
- B: 455 and 682 rpm
- C: 526 and 790 rpm

Mechanical tests description

So that, to achieve the proposal goal, eight extruded bars 2030 aluminum-copper alloy were mechanized using two coated carbide tools. After each process, hardness tests were realized on each sample to check if a perceptible variation in material properties has performed. As has been mentioned, every material sample was weighed to evaluate the total removed material and, thus, measuring the removed cutting material flow.

Boundary conditions: For tests A, B and, C, feed rate values of 0.1 and 0.18 mm/rev were selected such as are shown in Table 1. The operations were based on mechanizing, by means of turning process, of eight aluminum bars which have a length of 250 mm and a diameter of 50 mm. Also, a depth of cut of 3 mm was chosen in all processes.

Turning description: The turning process was made as a strict manner to prevent contaminations in the whole process.

The bar was fixed in the lathe in the best way possible to avoid bending phenomena. Then, revolutions were selected using the machine revolutions control device.

Afterwards, while the lathe worked, time gathering was performed with a chronometer.

Every day, two tests were realized by each edge and, by each cutting tool, so that each time that a process was finished, cutting tools were studied using SEM.

RESULTS

Regarding to completed assays for experimental campaign, following results were achieved.

Roughness

Roughness values of a type of material, above all, depend on the cutting tool and its geometry, of the accuracy of the machine and, of the used cutting conditions. Then this value gives an idea of the quality of the process.

ENSAYOS	C1	C2	C3	C4	C5	C6	C7	C8
Ra (µm)	1.83	2.15	1.93	2.57	2.18	2.05	1.92	2.21

Table 2. Achieved roughness using SM7 Profil Test for tests C

In this particular case study, roughness data were adapted to the mechanical process in a precise way. These roughness grades are about N7 which fits in ISO 1302:1992 standards [4].

Removed and uncut material flow

In terms of flow, considering the volume of material that will be removed in a minute, in mm^3/min, the following is assumed:

$$Q_c = a_p \cdot f \cdot S_c \cdot 10^3 \qquad (1)$$

with S_c as the cutting speed.

The value of uncut material flow is important because it gives an idea of the desirable value to be obtained. However, in reality this is almost never met, since the values obtained are always lower than expected.

		TEST A		
TEST	f mm/rev	Speed$_{Cii}$ m/min	Q_c mm^3/min	t_{ii} s
1	0.1	63.62	19085	368
2	0.1	63.85	19156	359
3	0.18	63.38	34226	212
4	0.18	62.91	33972	215
5	0.1	94.56	28369	247
6	0.1	94.88	28463	245
7	0.18	94.56	51063	142
8	0.18	94.17	50851	143

Table 3. Uncut material flow from the test A

Due to space reasons the totally of the tables have not been included in this article.

The uncut material flow (Table 3) is calculated by the expression (1) only taking into account the cutting speed and the cutting surface, assuming in each case f=const and a_p=const. Notice how in each test, the flow decreases as the time increases. This occurs because, although the cutting speed is maintained substantially constant, the speed increases and thereby more material per revolution is removed.

Considering the removed material flow, that is, the volume of material formed in a minute (mm^3/min), the results are shown in the table below:

		TEST A		
TEST	f mm/rev	S_{Cii} m/min	Q_v mm^3/min	t_{ij} s
1	0.1	63.62	17279	368
2	0.1	63.85	17277	359
3	0.18	63.38	30481	212
4	0.18	62.91	30674	215
5	0.1	94.56	26532	247
6	0.1	94.88	26884	245
7	0.18	94.56	45676	142
8	0.18	94.17	46100	143

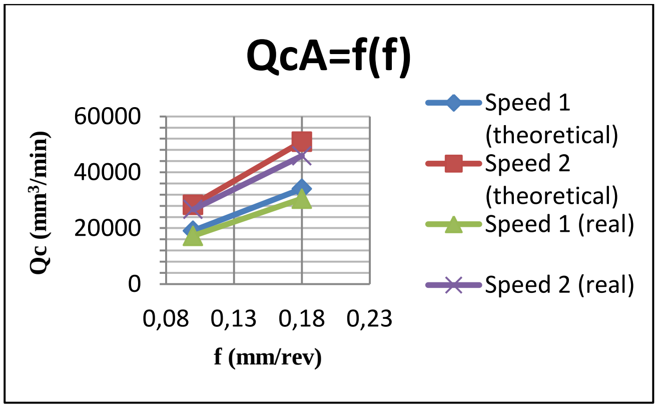
Table 4. Removed material flow from test A

Removed material volume is obtained experimentally from the process through the weight difference that has had the workpiece and through the material density calculated from the geometry of the bars. It should be pointed out that the material density is calculated as the average of all the independent densities of the samples, this coincides with the expected for this material (2.79 g/cm3).
Then removed material volume is calculated using the following expression:

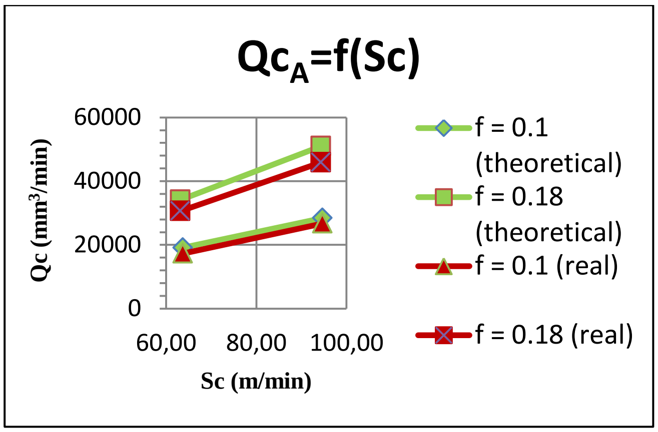
$$Q_v = \frac{WI_{ij} - WF_{ij}}{\rho}\ (mm^3) \qquad (2)$$

WF_{ij} and WI_{ij} are the initial and final weight, respectively, in each operation.

The relationship between theoretical uncut material flow and real removed material flow which is function of the feed rate and cutting speed, respectively are presented in the following graphs. As experience shows, these curves vary in a quadratic form, however, due to only two types of assays were performed (feed rates between 0.1 and 0.18 mm, cutting speed between 63 and 92 m / min), the curves resemble the linear variation. In contrast, increasing the values of the cutting variables, corroborate the steepening described by experience. Therefore, it is deduced that the obtained data agree closely with the results provided by the theory of metal cutting.



Graph 1. Removed and uncut material flow associated with cutting feed rate



Graph 2. Removed and uncut material flow associated with cutting speed

Tool wear

The next comparative image shows the outcomes achieved using SEM. This is related with the tool wear obtained.

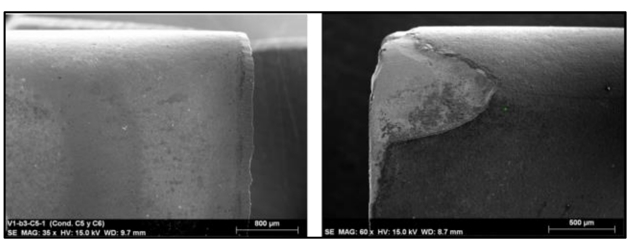


Fig. 1. Serious flank wear (right image) VS cutting tool from the test C

In the picture on the left, it is shown the cutting tool edge related to machining C5/C6 with the most severe conditions of the first carbide tool. In the picture on the right, it is displayed a cutting tool used to machine a steel for 6 hours of work.

At the tool on the right it is observed a hard flank wear as a result probably from oxidation and friction. The curve is about 950 microns in length to the apex. It can be seen how the coating has disappeared leaving the bare surface of the inner compound. Also, it is noticed the crater wear on the left side of the image that is due to the diffusion mechanism generated by high working temperatures in the tool. In contrast, at the tool on the left no wear is observed due to reduced tests performed by it.

CONCLUSIONS

A methodology to make an accurate machinability study was evaluated and was concluded. In the same way, assessment of cutting variables and how have to be these and, how they take into account in the process was accomplished.

We have defined a methodology to characterize the aluminum-copper alloys for aeronautical use, from the point of view of machinability that allows to student of last year career develop an experimental work, maintain the repeatability of its essays and provide scientific rigor to the conclusions.

The feasibility of making small-scale research at the university could be a great chance to those trainees and new researchers who find the investigation interesting. The learners could find out new ways of working in a methodical environment which will encourage them to think outside the box.

Now it is the moment to pass the torch to other students and teachers who want to start another study related to this and awakening the curiosity for the research and development.

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