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Chip arrangement in the dry cutting of aluminium alloys

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ABSTRACT

Purpose: The aim of the research is make a first analysis of the chip formed in the dry turning process of AA2024 (Al-Cu) and AA7050 (Al-Zn) aluminium alloys.
Design/methodology/approach: The methodology has consisted of proving a series of parameters combinations: feed rate, f, cutting speed, v, and depth of cut, d, and of analysing the different types of chip appeared during each one of them.
Findings: A single classification, specific for the studied alloys, has been proposed. This classification has been built in a similar way to those recorded in ISO 3685 standards. As a result, it has been able to realise that a direct correspondence with that standards does not exist. Besides, the relationship between chip arrangement and workpiece surface finish has been studied through the comparison between chip form and Ra parameter for different cutting conditions.
Research limitations/implications: A possible future work is the development of a general standard, like ISO 3685, for the rest of the aluminium alloys.
Practical implications: The relationship found between chip arrangement and workpiece surface finish has an important practical implication since it allows selecting the best cutting condition combination from the points of view both the security and the economy for the established requirements in each case.
Originality/value: The paper is original since the bibliographical review has allowed testing that, although works about these themes exist, none approaches the problem like it has been made in this work.
Keywords: Manufacturing and processing; Machining; Dry turning; Chip arrangement; Aluminium alloys

1. Introduction

Most of the structural components of airships and aerospace vehicles need different machining operations during their manufacturing process, mainly for the assembly requirements. Generally, they have to present both a high dimensional precision and a quality surface high level. These factors are required in order to obtain an adequate performance of the overall device. The aforementioned components are usually made of light alloys, mainly based on aluminium or titanium. This is due to their very good relationship between their weight and their mechanical properties [3-7,12-21,25-29].

However, these materials can commonly show problems associated with the heat generated during the machining process that reduces their machinability and increases the temperature [8,9]. This fact is specially injurious for the tool because of an increase of temperature can provoke that its physical and chemical properties can be reduced and, as a consequence of that, its life decreases [4-7,10-20,22-24].

Until few years ago, the thermal energy involved in a machining process has been evacuated by means of lubricants and coolants, diminishing, in this way, the temperature in the work area. However, these cutting fluids are polluting and increase the total cost of the process considerably. Besides, the great social preoccupation about the environmental conservation has made necessary to develop cleaner production technologies. The simplest method consists on eliminating the cutting fluids. This method is usually known as *dry machining*. Nevertheless, the total suppression of these fluids involves to work under very aggressive conditions [4-7,16-20,22,27-29].

Such situation makes necessary to look for new tool designs or, more cheaply, for combinations of cutting parameters [22] and types of tools [10,11,21-24] that optimise the machining process, i.e., that allow obtaining pieces with a good dimensional precision and a high quality surface level, with a cost as low as possible and, of course, under secure conditions for workers and equipments [1,2,8-11].

In order to achieve this objective an intense research effort can be appreciated in the literature. In particular, in our labs, some previous works has been carried out [32, 33]. So, in a first stage, a series of dry machining tests of short duration (no longer than ten seconds) were made with workpieces of different alloys of aluminium (AA2024 and AA7050) and titanium (Ti 6Al 4,5V). In these studies, different alterations of the tools geometry, such as Built-Up-Edge (BUE), Built-Up-Layer (BUL), flank wear and crater wear, were characterised as a function of the machining time and the value of the used cutting parameters [1,17,20,27-29].

Afterwards, systematic studies about the behaviour of tools and pieces for: different combinations of materials, cutting parameters and machining processes were made, so as to establish selection criteria of tools and values of cutting parameters that allow obtaining pieces in a functional and competitive way. In particular, a surface roughness analysis versus machined length of AA2024 and AA7050 aluminium pieces obtained by turning process was made. The parameter selected to define the surface quality of the pieces was the *arithmetical average roughness*, *Ra*. Its value was analysed for a series of test-pieces obtained under different combinations of the cutting parameters values (cutting speed, feed rate and depth of cut). The obtained results allowed establishing for each set of cutting parameters the *Ra* prospective value range [4-6,17,20,27-29].

One of the aspects notably affecting the efficiency of machining processes is the monitoring and control of the chip form because it can affect to surface finish, workpiece accuracy and tool life. Then, knowledge of the cutting parameters that allow the formation of favourable shapes chip that can be easily and reliably evacuated from the working zone, is very important since it could contribute to the improvement of machining process reliability, the production of high quality machines surface, the increase of productivity, and enhancement of operation safety (including operator safety) and tools and machines protection.

In this work, the relationship between each combination of the cutting parameters and the type of formed chip in the machining of AA2024 and AA7050 aluminium alloys has been analysed. Furthermore, its relation with *Ra* has been analysed as well.

2. Experimental layout and materials

AA2024 and AA7050 aluminium alloys were used in the present study. Their compositions in percentage of mass have been included in Tables 1 and 2 respectively.

The workpieces were bars of 90 mm diameter and 170 mm length. This is the maximum length of the work area in the used CNC machine tool: an EMCOTurn 242 horizontal lathe equipped with numerical control EMCOMETRIC TM02, Figure 1. Cutting operations made in each test were longitudinal turning.

Each one of such operations was made under a certain combination of the parameters: feed rate, f, cutting speed, v_c, and depth of cut, a_p. Particularly, the used f values were 0.05, 0.10 and 0.30 mm/rev; the v_c ones, 43, 65, 85, 125 and 170 m/min, and the a_p one, 1 mm since, in order to avoid the depth influence of the tests, this parameter was fixed to a value sufficiently higher than feed rate [17,34].

TiN coated WC-Co turning inserts were employed as cutting tool in the tests. Concretely, from the SECO manufacturer (code DCMT11T308-F2 TP1000).

Roughness measurements were made with a MAHR profilometer/roughness-meter, model Perthometer M1, Figure 2. It is formed by a PFM drive unit and a stylus NHT 6-100. Perthometer Concept software was used in the roughness evaluation.

The surface roughness of the workpieces was characterized by the *arithmetical average roughness*, *Ra* [14]. Their values were measured along $\pi/2$ separated four lines verified in each one of the test-pieces, and their average value was calculated for every test-piece like it was shown in previous works [4-6,17,20,27-29].

The tests monitoring was made with a digital camera Cool Pix 995 Nikon so that, along all its stages, graphic documents exist and they can be analysed after the process is finished; especially, movies of all machining processes and pictures of the tools and the different types of chips obtained in each one of them have been taken.

Table 1.
Composition (% mass) of AA2024 alloy.

Cu	Mg	Mn	Si	Fe	Zn	Ti	Cr	Al
4.00	1.50	0.60	0.50	0.50	0.25	0.15	0.10	Rest

Table 2.
Composition (% mass) of AA7050 alloy.

Cu	Mg	Zn	Cr	Fe	Mn	Ni	Si	Ti	Zr	Al
2.60	2.37	6.56	0.03	0.09	0.05	0.01	0.06	0.018	0.10	Rest

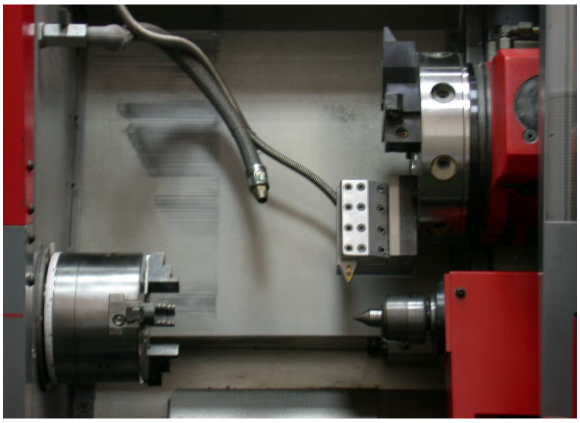


Fig. 1. CNC horizontal lathe employed in the dry turning tests: detail of the work area.

Fig. 2. Profilometer/roughness-meter used in the surface quality measurements.

3. Results and discussion

Figure 3 reproduces the chip types recognised in the standard ISO 3685 [13]. Chips obtained from the tests carried out on the AA2024 and AA7050 alloys have been classified according to the chip types shown in that standard.

It is important remark that this standard was developed for turning steel and cast iron workpieces and, therefore, at this first analysis, only the shape of the chips has been taken into account but no the classification in the two big categories, favourable and unfavourable, given by ISO. The reason is the next one. It has been detected that such classification, good for the steels and cast irons, can not be adequate for the aluminium and its alloys [36,37].

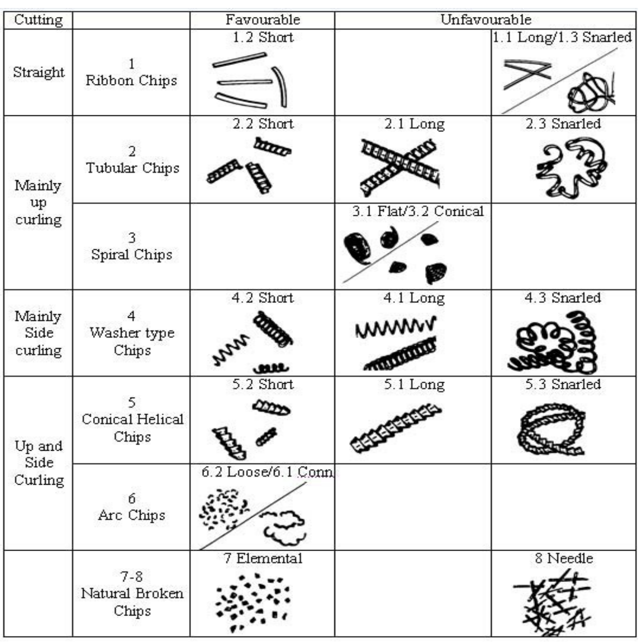


Fig. 3. Chip form classification. Adapted from [20]

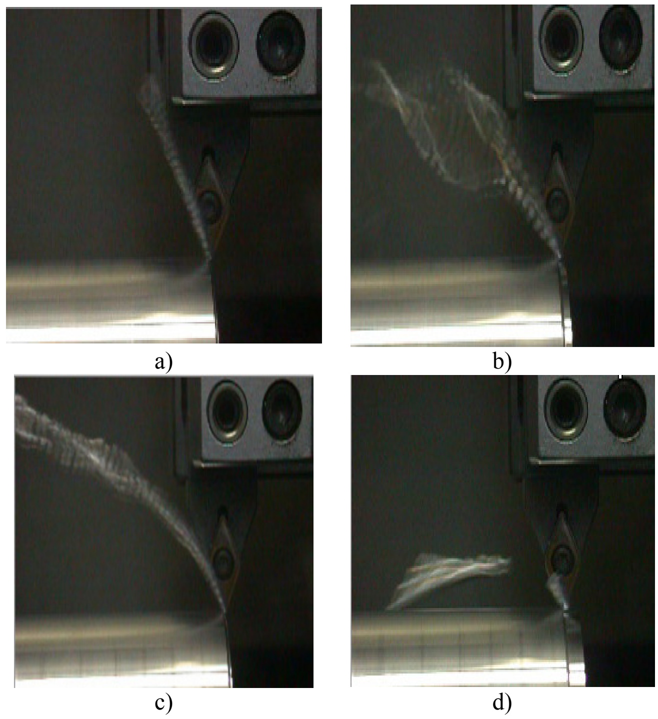


Fig. 4. Detail of the break of a long chip obtained for the test number 4 of AA2024 alloy (65 m/min of cutting speed, 0.05 mm/rev of feed rate and 2 mm of depth of cut).

Table. 4.
Chip arrangement for AA2024 alloy.

Test N.	v (m/min)	f (mm/rev)	Chip form
1	43	0.05	Long 5.1
2	43	0.10	Short 5.2
3	43	0.30	Conn 6.1 / Short 2.2
4	65	0.05	Long 4.1
5	65	0.10	Short 5.2
6	65	0.30	Conn 6.1 /Short 2.2
7	85	0.05	Snarled 2.3
8	85	0.10	Snarled 2.3
9	85	0.30	Short 2.2
10	125	0.05	Snarled 2.3
11	125	0.10	Snarled 2.3
12	125	0.30	Conn 6.1
13	170	0.05	Snarled 1.3
14	170	0.10	Snarled 2.3
15	170	0.30	Conn 6.1

Table. 5.
Chip arrangement for AA7050 alloy.

Test N.	v (m/min)	f (mm/rev)	Chip form
1	43	0.05	Snarled 1.3 /Snarled 5.3
2	43	0.10	Snarled 2.3
3	43	0.30	Long 2.1 /Snarled 2.3
4	65	0.05	Snarled 4.3
5	65	0.10	Snarled 4.3
6	65	0.30	Short 4.2
7	85	0.05	Snarled 1.3
8	85	0.10	Snarled 4.3
9	85	0.30	Snarled 4.3
10	125	0.05	Snarled 2.3
11	125	0.10	Snarled 4.3
12	125	0.30	Long 4.1
13	170	0.05	Snarled 4.3
14	170	0.10	Snarled 4.3
15	170	0.30	Snarled 4.3 /Long 2.1


a)

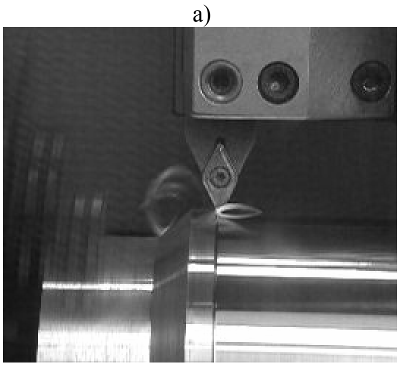

b)

Fig. 7. Frames of the turning process of AA7050: a) test number 7; b) test number 14.

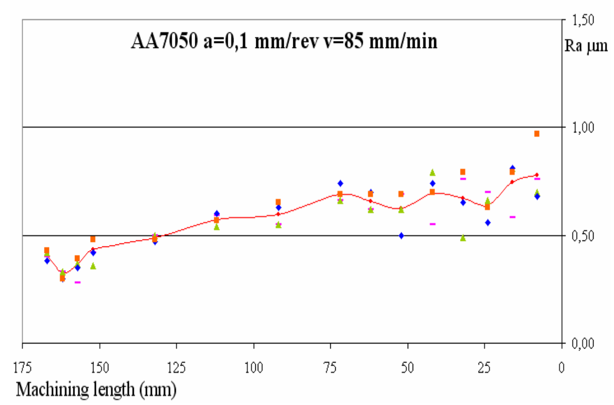
For example, a long aluminium chip (similar to the 2.1, 4.1 or 5.1 cases collected in Figure 3) is not unfavourable, at least, from the point of view of the machining security because it breaks before reaching a dangerous long. However, the continuous knocking of the chip pieces against the workpiece and the tool is desired, neither for the surface quality maintenance nor for the tool integrity, as it can be appreciated in Figure 4. The chips obtained in both cases are shown in Figures 5 and 6 and the arrangement made of them in Tables 4 and 5 respectively.

Figure 7 shows two different types of chip found during the turning of the AA7050 aluminium. In figure 7a, the snarled 4.3 chip can be classified in the AA7050 aluminium case as unfavourable in the same way that for the ISO 3685.

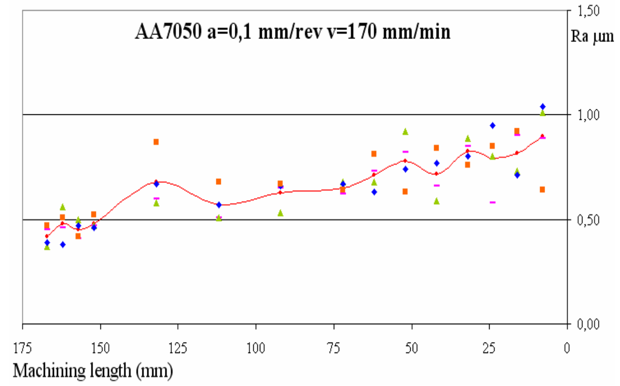
However, in figure 7b, it can be seen a snarled 1.3 chip, classified like unfavourable in the steels and cast iron machining, that it is not absolutely unfavourable in the aluminium case, because does not imply any loose of security during the machining.

Then, it will be necessary to analyse all the cases presented in this work so as to establish a chips classification of aluminium and aluminium alloys material similar to the existent ISO 3685 for the steels. Furthermore, in agreement with the considerations recorded in [36,37], it cannot be established a machinability criterion based on the chip arrangement for aluminium alloys.

Individual classifications will allow knowing the cutting parameters combinations that provide dangerous chips for the machining of specific alloys in a set of cutting conditions.



a)

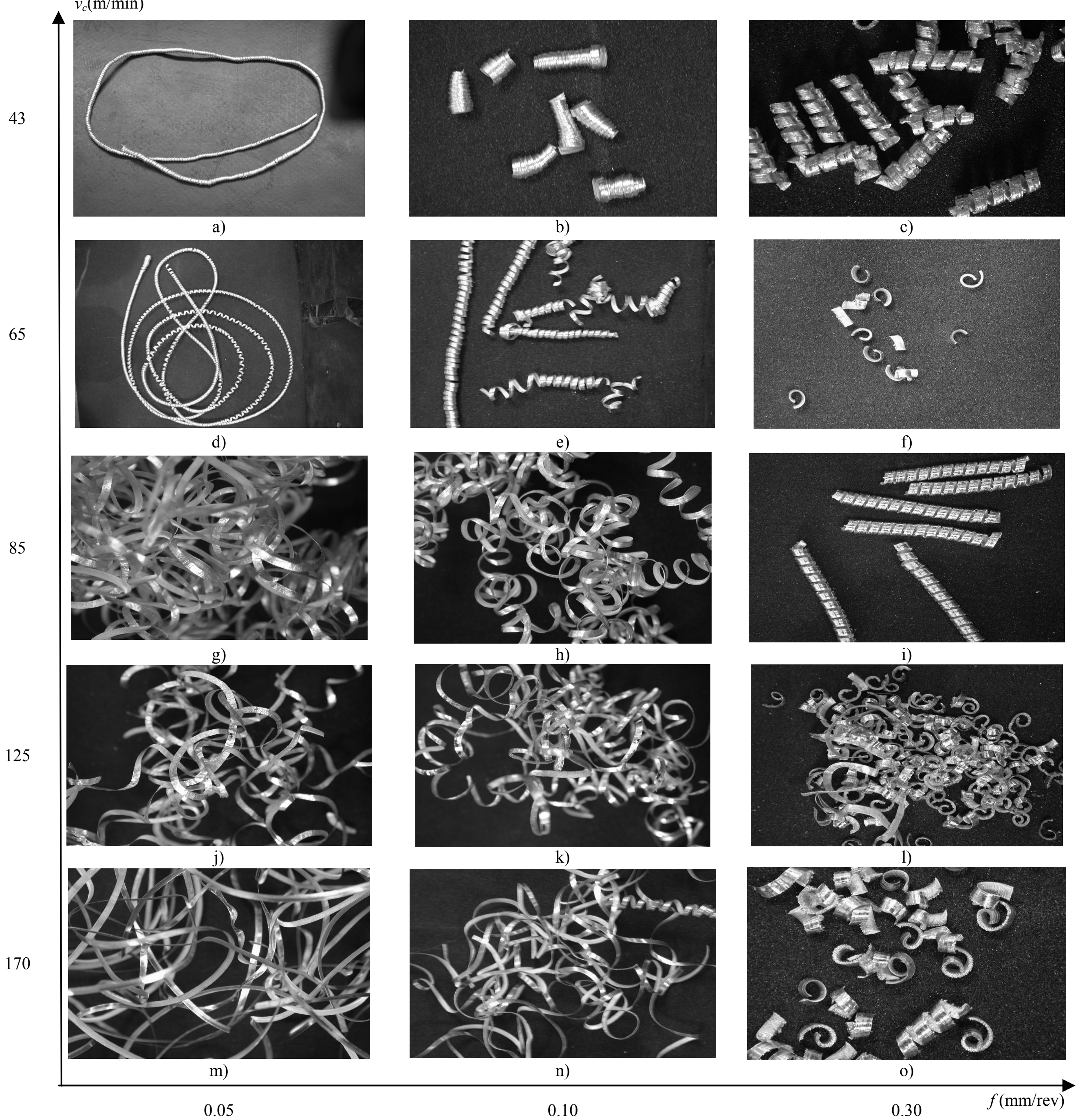


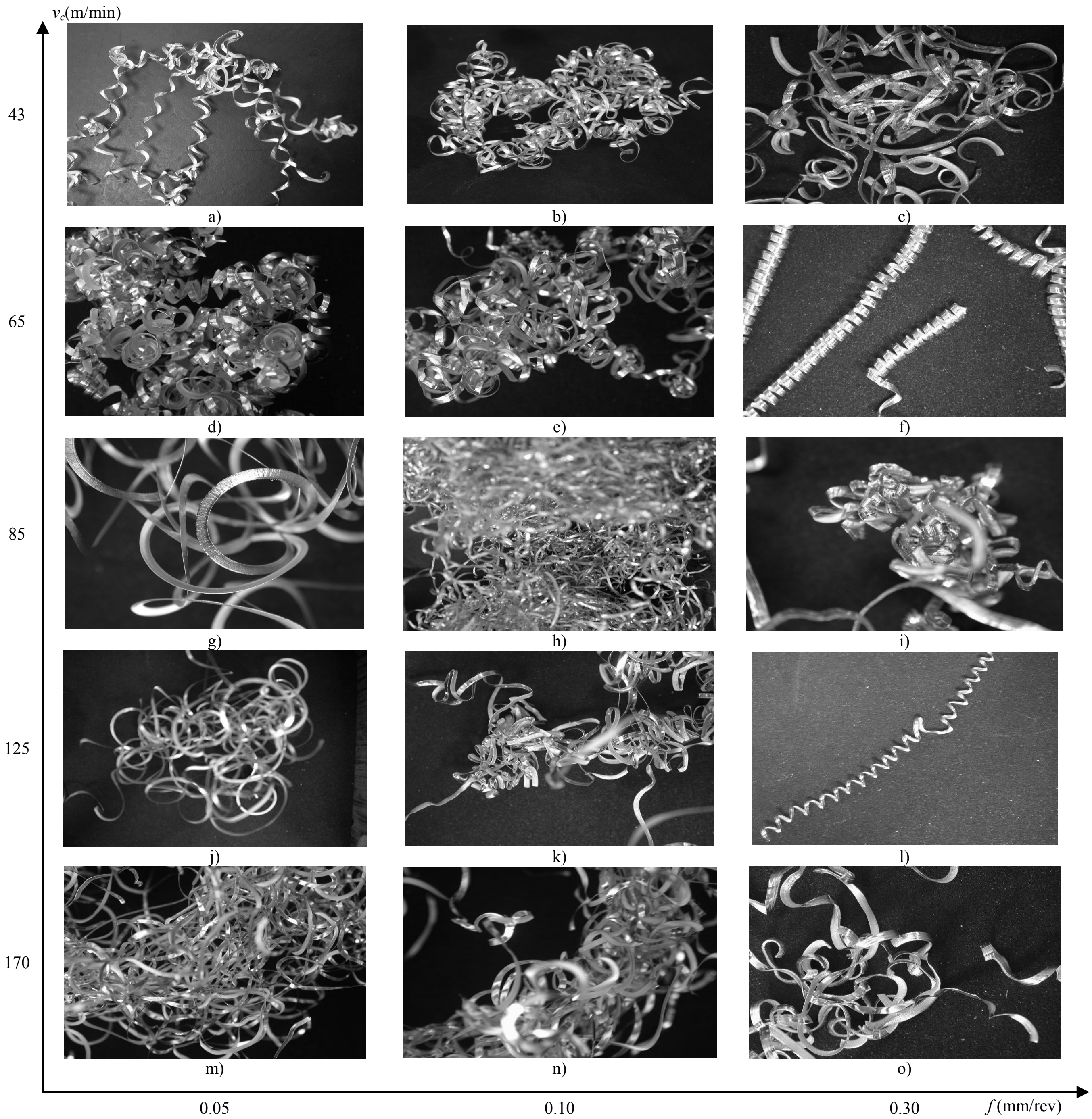
b)

Fig. 8. Average roughness parameter *Ra* as a function of the machining length acquired on AA7050 workpieces after: a) test number 7; b) test number 14.

For example, a cylinder piece of AA7050 alloy with a surface finish characterised by a *Ra* (μm) ∈ [0.450; 1.000] can be obtained by means of different parameters combinations. In particular, by those used in the test represented in Figures 7 and 8. In them, it is possible to see that the cutting conditions given in 8a) and in 8b) produce similar *Ra* but, the first one is more dangerous than the second one due to the type of generated chip. The snarled 4.3 chip obtained in test number 14 for f=0.10 mm/rev, v_c=170m/min and a_p=1 mm is not good for the machining security, the surface quality and the tool life. While, the snarled 1.3 chip obtained in test number 7 for f=0.05 mm/rev, v_c=125m/min and a_p=1 mm is, at least, secure.

Then, taking into account the pieces surface quality results obtained in previous works [4,6,11-14,16-33] as the shown ones in Figure 8 for the same test number that the turning shown in Figure 7, it will be possible to select the most favourable combination of cutting parameters to obtain a certain surface roughness under the best security conditions.





4. Conclusions

In this work an analysis of the type of chips found in the machining of AA2024 (Al-Cu) and AA7050 (Al-Zn) alloys has been made.

Chips produced under different cutting parameters combinations have been classified by their shapes according to the ISO 3685, specific standard for steels and cast iron.

A chips classification in favourable and unfavourable similar to that given by ISO has been proposed. It has been possible detect that a direct correspondence between the chips classification of the analysed aluminium alloys and the collected one in the ISO standard for steels and cast iron does not exist.

Finally, the relationship betweeen chip arrangement and workpiece surface finish has been studied through the comparison between chip form and *Ra* parameter for different cutting conditions

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