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Surface roughness of AA7050 alloy turned bars Analysis of the influence of the length of machining

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Abstract

In this work, a surface roughness analysis versus machined length of AA7050 aluminium pieces obtained by turning process has been made. The parameter selected to define the surface quality of the pieces has been the arithmetical average roughness, R_a. Its value has been analysed for a series of test-pieces obtained under different combinations of the cutting parameters values (cutting speed, feed and depth of cut). The obtained results allow affirming the R_a value, in general, has tendency to decrease when the machining length increases. Within this general tendency, R_a values increase slightly with the cutting speed and more strongly with the feed.

Keywords: Surface quality; Surface roughness; Turning; Machined length; AA7050

1. Introduction

Light alloys, mainly aluminium and titanium based alloys, have been used in the production of structural components of airships and aerospace vehicles, due to the good ratio between their weight and their mechanical properties [1–7]. Generally, those components and their surfaces finishing have to present high quality requirements [8–10]. Their production usually involves different types of processes. Among them, it is possible to remark removal material processes such as drilling or turning [11].

In spite of the importance that light alloys have from the strategic point of view, it is not easy to find in the bibliography, neither systematic studies nor clear approaches about their machinability. The scarce studies, carried out until the moment, show that aluminium and titanium alloys present, in general, problems associated with the machinability. These problems are basically related to the heat that is generated during the machining process [12,13]. This heat originates an increase of the temperature and this is specially injurious for the tool since its life decreases with the increment of that [12,14].

Until few years ago, lubricants and coolants have been commonly employed for evacuating the thermal energy involved in a machining process and, also, for diminishing the temperature in the work area. However, these cutting fluids can pollute and increase the total cost of the process considerably [13–16]. This, along with the growing social preoccupation about the environmental conservation, has made necessary to develop new cleaner production technologies. According to this philosophy, the most radical method to carry out a sustainable manufacturing is to eliminate cutting fluids, giving rise to the so-known dry machining. However, the total suppression of these fluids involves to work under very aggressive conditions [13–16].

This new situation makes necessary to look for combinations of cutting parameters and types of tools that optimise the machining in those extreme work conditions with the purpose of obtaining a quality level in products according to the demanded specifications and with a cost as low as possible.

In order to establish selection criteria of tools and values of cutting parameters that allow obtaining pieces in a functional and competitive way, it is necessary to carry out systematic studies about the behaviour of tools and pieces for different combinations of materials, cutting parameters and machining processes.

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In this context, the results presented in this work, are part of a study focused to analyse the machinability of light alloys under dry cutting conditions. In particular, the main objective of this work is to analyse the surface quality evolution versus the turned length of AA7050 bars and, if possible, to establish the existing relations between the alterations of the tool geometry, the samples surface roughness and the values of the cutting parameters.

The parameter selected to define the surface quality of the pieces has been the arithmetical average roughness, R_a; the most extended parameter in the literature for the determination of the superficial quality of the mechanized pieces [7]. On the other hand, the results have been compared with those obtained in a similar study made with AA2024 aluminium.

Both studies have its origin in previous works made on a series of machining tests of short duration (no longer than 10 s) and they are framing in a deeper parametric analysis about aluminium alloys [11]. First tests were made with different light alloys of aluminium (AA2024 and AA7050) and titanium (Ti 6Al 4,5V), tools of wolfram carbide (WC–Co) coated of titanium nitride (TiN) and under dry cutting conditions as well. Such studies revealed that, during the machining process, the tool suffers different alterations in its geometry as, for example, built-up-edge (BUE), built-up-layer (BUL), flank wear and crater wear. Being, all of them, more or less accused in function of the machining time and the value of the used cutting parameters [14,17,18].

2. Tests definition

As it has been aforementioned, the present work is framed within a series of studies in which there are involved different materials, types of tools and cutting conditions. Then, in order to systematize all the steps to follow until obtaining the proposed objectives, a work methodology has been developed [4,19]. Rarely, a set of steps as the proposed in this research methodology can be found in the literature. Because of this, in order to give to know it and to facilitate possible works of the same nature, in this paper, a brief description of the procedure has been considered interesting to be introduced. Thus, next subsections contain the main steps of such methodology.

2.1. Previous activities to the machining operations

These activities consist on the identification of the used resources and the preparation of the protocols both to calculate cutting parameters values and to registry data and observations of the machining process.

2.2. Turning tests

In each test, a piece, with a length as long as possible according to the dimensions of the numerical control machine-tool used in the experimental procedure, is machined under certain conditions of feed, cutting speed and depth of cut.

The process should be monitored so that, along all its stages, graphic documents exist and they can be analysed after the process is finished. Finally, the test-pieces should be properly identified in order to make a suitable control.

2.3. Previous activities to the roughness measurement

In order to systematize test-pieces roughness measurements, first of all, the measurement process has to be defined. This is, basically, to measure the roughness along four lines separated $\pi/2$ radians in each one of the test-pieces. So, to carry out the measurements, it is necessary to dispose properly a series of auxiliary elements and measure instruments, and to verify that all of them are in perfect state.

2.4. Roughness measurement

According to the measure process defined previously, roughness measurement have to be made along the maximum machined length. In this measure process, a set of data (xi, zi) from the surface geometry of the piece is obtained. They have to be recorded in the suitable format so that they can be used later by the available software.

2.5. Data processing and analysis of results

A first approach to the study of the surface quality of the machined samples has been made in this work.. The *arithmetical average roughness*, R_a, has been selected as the parameter to be analysed.

According to ISO standards [20], this parameter is defined like *the arithmetical average of the absolute values of the deviations of the profile of roughness R* and is expressed mathematically by means of the equation (1):

$$R_a = \frac{1}{l_m}\int_0^{l_m} |z(x)|\,dx \tag{1}$$

Data processing consists on calculating and plotting the average value of R_a in the different sections selected in the four lines mentioned before.

Data analysis is made qualitatively, in terms of the evolution shown in the graphs, and quantitatively, by comparison of the obtained values for the different used parameters.

2.6. Scanning electron microscopy (SEM)/energy dispersive spectrometer (EDS) analysis of tools

From the obtained results, a tools pre-selection must be made. The selected tools are analysed through scanning electron microscopy and energy dispersive spectrometer techniques in order to characterise the changes in the tools surface.

Table 1
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 machine tool employed in the experimental stage of the work.

3. Experimental layout and materials

The material used in the tests was the AA7050 aluminium alloy whose composition in percentage of mass has been included in Table 1. Particularly, workpieces used in the tests were bars of 90 mm of diameter and 170 mm of length, since this is the maximum length of the work area in the CNC machine tool used.

The cutting tests were performed in an EMCOTurn 242 horizontal lathe equipped with numerical control EMCO-METRIC TM02, Fig. 1. Cutting operations made in each test were longitudinal turning.

Table 2
Cutting conditions

v (m/min)	*a* (mm/rev)	*p* (mm)
43	0.05	2
65	0.10	
85	0.3	
125		
170		

Fig. 2. Roughness measurement equipment layout.

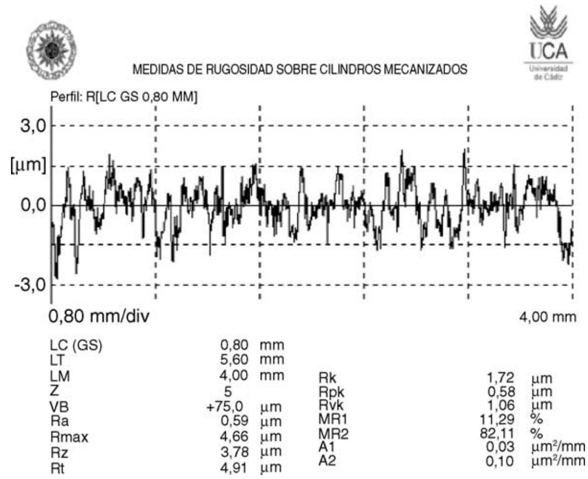

Fig. 3. Protocol for roughness measurement.

TiN coated WC–Co turning inserts were employed as turning tool in the tests.

Cutting parameters values have been collected in Table 2. In order to avoid the depth influence of the tests, this parameter was fixed to a value sufficiently higher that feed [11,21]. All possible combinations of those values giving up to a total of 15 cutting tests.

Roughness measurements were made with a MAHR profilometer/roughness-meter model Perthometer M1. Roughness measurement deviceis formed by a PFM drive unit and a stylus NHT 6–100, Fig. 2.

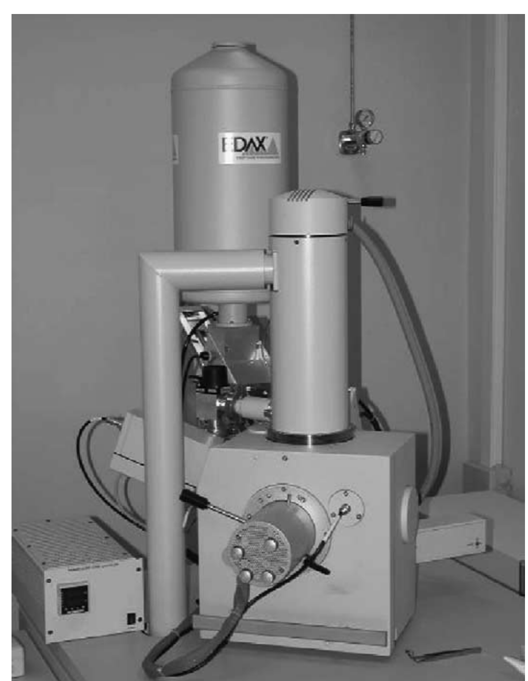

Fig. 4. Scanning electron microscope, Quanta 200.

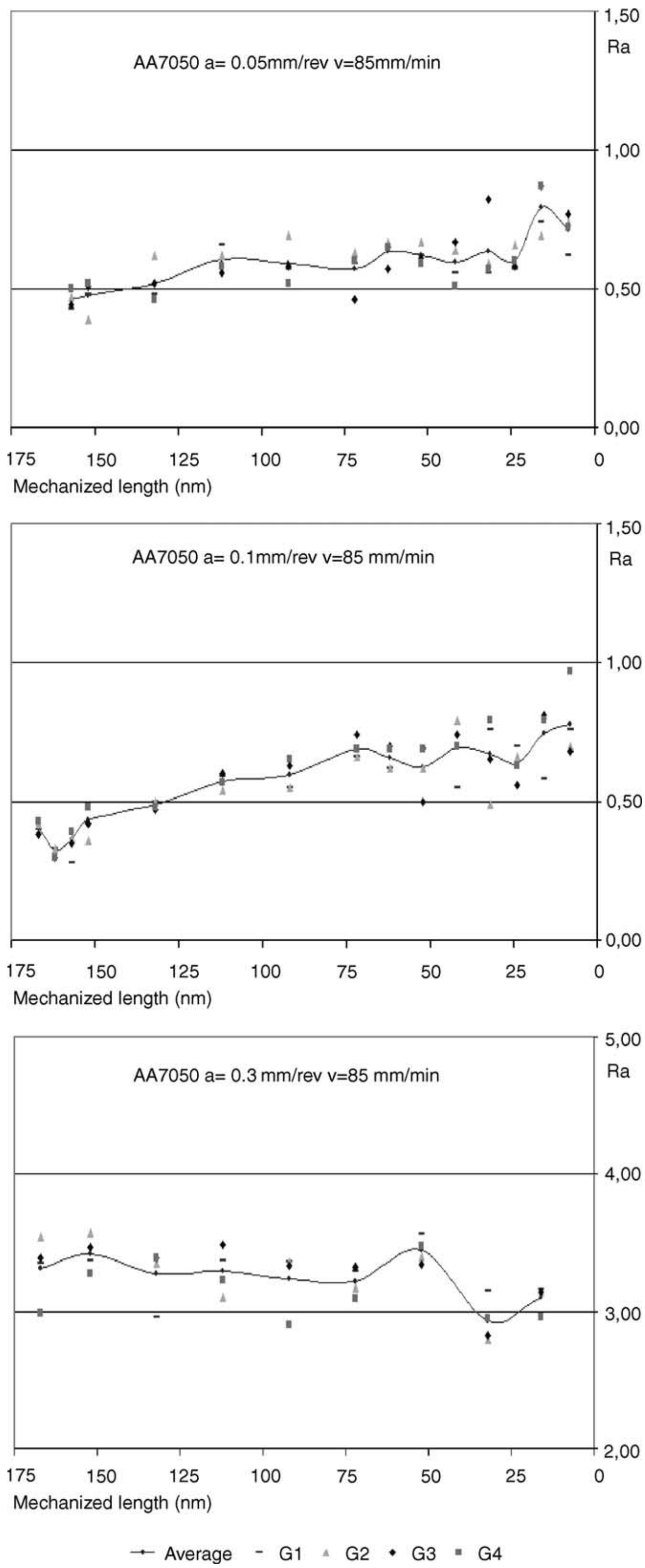

Fig. 5. R_a (μm) values versus mechanized length for different feed values.

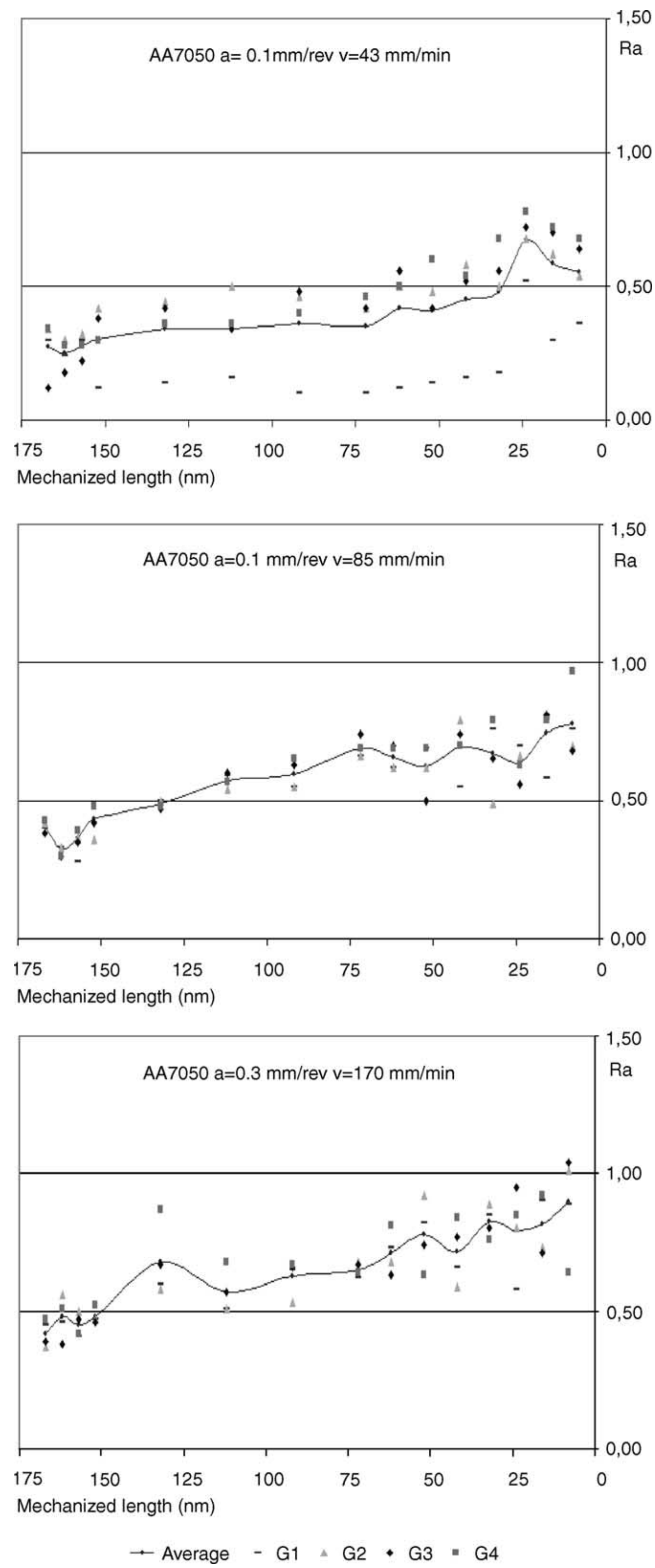

Fig. 6. R_a (μm) values versus mechanized length for different speed values.

Additionally, Perthometer Concept software allows carrying out roughness evaluation by means of protocols. One of them is shown in Fig. 3.

In this figure, the roughness profile, R, and the selected parameters l_c, l_t, l_m, z, R_a, R_{max}, R_z and R_t can be observed. Besides, Perthometer Concept allows an easy and flexible files administration of the measurement results.

In order to carry out the monitoring of the tests, a digital camera Cool Pix 995 Nikon has been used.

For SEM/EDS analysis, a Quanta 200 scanning electron microscope, attached to an energy dispersive spectrometer analyser has been Fig. 4.

4. Results and discussion

Fig. 5 plots the R_a values versus the machined length for a cutting speed of 1.42 m/s (85 m/min) and feed values of 0.05, 0.10 and 0.30 mm/rev, respectively. The R_a values obtained along four lines verified in each one of the test-pieces, and their average value have been both plotted. In order to appreciate better its variation with the length, the R_a average value has been plotted by means of a continuous line.

Looking at this figure, it can be observed as R_a values present a certain tendency to decrease with the mechanized length for low and medium feed values, and they are approximately constant for high feed values.

On the other hand, in Fig. 6, R_a values versus mechanized length have been plotted for cutting speed $v = 0.72$, 1.42 and 2.83 m/s (43, 85 and 170 m/min) and a feed value, $a = 0.10$ mm/rev. In this case, it can be seen that R_a decreases versus machined length reaching high values if speed increases.

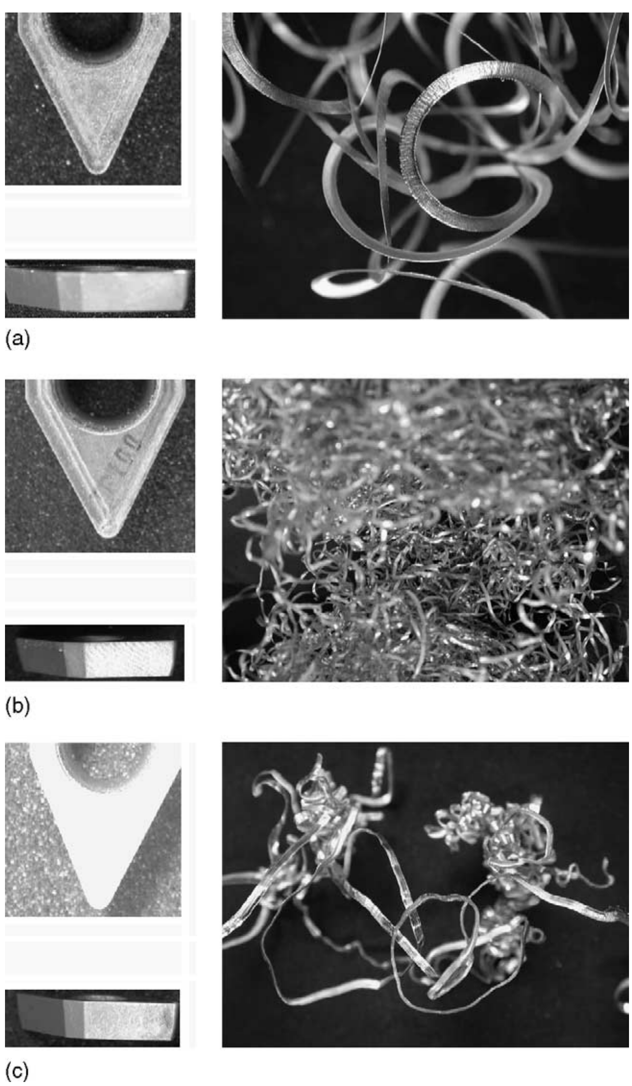

Fig. 7. Macrograph of the used tools and obtained chips during the processes made under the next conditions: $v = 85$ m/min and: (a) $a = 0.05$ mm/rev; (b) $a = 0.10$ mm/rev and (c) $a = 0.30$ mm/rev.

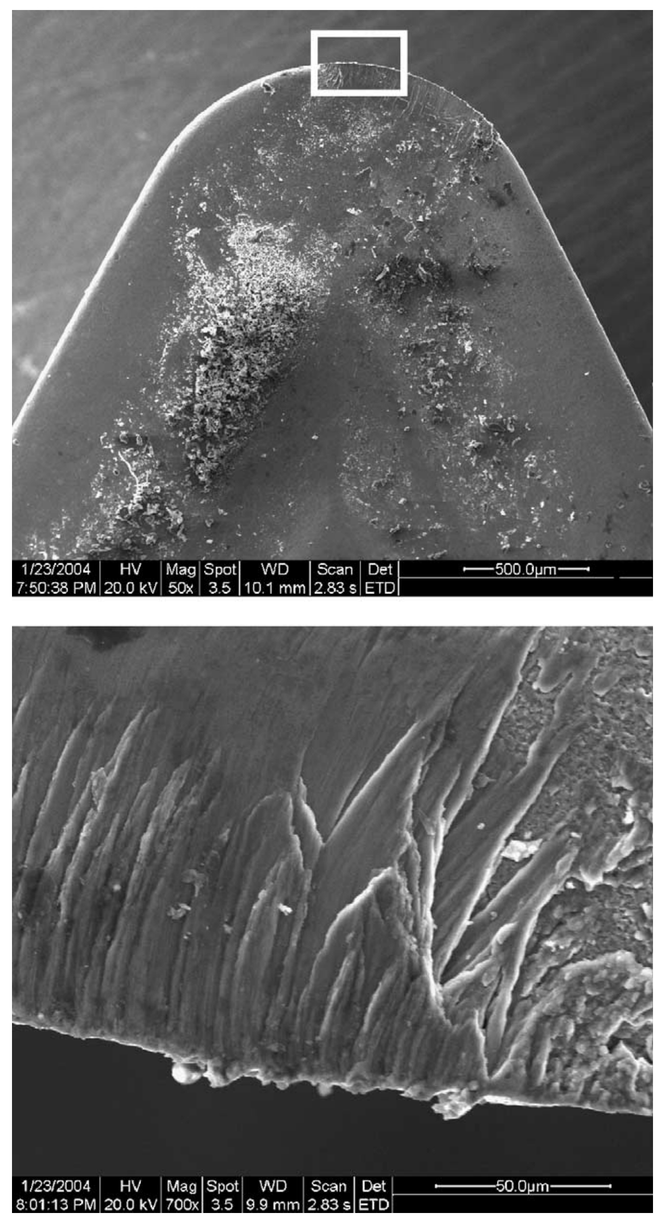

Fig. 8. (a) Adhesion effects on the tool. (b) Edge detail.

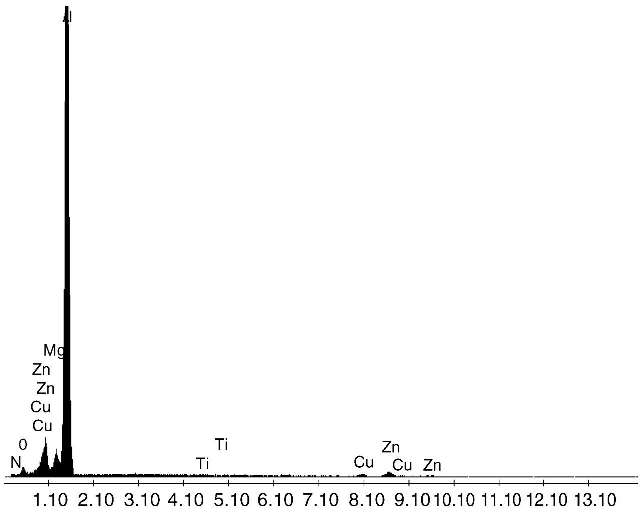

Fig. 9. Energy Dispersive Spectrometer analysis of the tool edge used at $v = 0.72$ m/s, $a = 0.05$ mm/rev and $d = 2$ mm.

All these observations can be explained considering alterations of the tool geometry during the turning process.

Fig. 7 collected the macrographs of the used tools and the obtained chips during the three turning processes shown in Fig. 5. As it can be appreciated, an incorporation of the workpiece materials has took place during the turning process. This incorporation can be located in two well-defined zones of the tool: the edge and the rake face. The first one is known as built-up-edge and the second one, as built-up-layer.

Deeper analysis by scanning electron microscopy, Fig. 8, showed that the material is deposited as a multiplayer. Compositional features of the upper layer was characterised by energy dispersive spectrometry, Fig. 9, showing that the material adhered to the tool comes from the machined workpiece and its composition is very similar. In further explanations about the formation of this metallic coating which can be found in [14,22], it can be concluded that in the beginning of the process BUL is formed by a combination of thermal and mechanical causes.

When BUL is just formed, BUE begin to be developed and is growing to a critical thickness. Once reached this thickness, BUE is mechanically extended onto the rake face of the tool increasing the thickness of BUL and forming the multiplayer detected in Fig. 8.

A second observation can be made on the Fig. 7. In effect, it is possible to see how the chips obtained in each case present different morphology. Thus, for low feed values the chip is longer and more flexible than for higher feed values where it appears shorter and harder. As longer is the chip the probability of damaging the workpiece increases and, as a consequence of this, also the roughness does it. However, as it can be observed in the figures, feed value is more influent that long of chip.

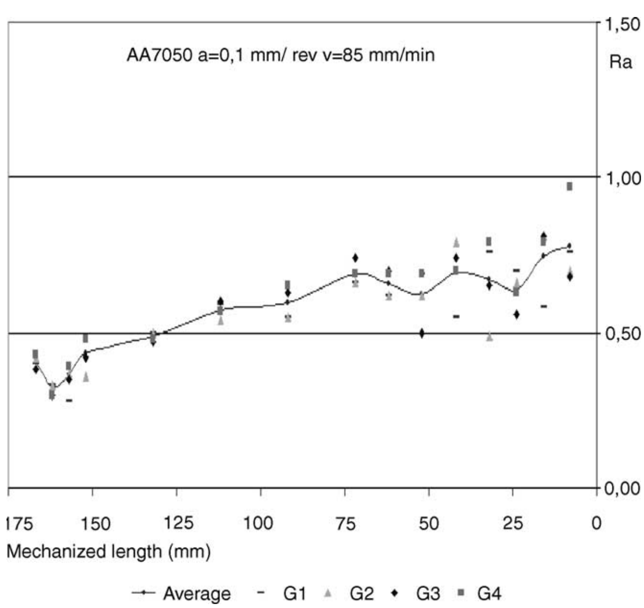

Fig. 10. R_a staggered diminution.

Table 3
R_a values range (μm) for AA7050

Feed (mm/rev)	Speed (m/s)		
	0.72	1.42	2.83
0.05	0.740–0.280	0.870–0.390	0.920–0.350
0.10	0.780–0.100	0.970–0.280	1.040–0.370
0.30	4.670–3.760	3.570–2.800	3.930–3.570

Table 4
R_a values range (μm) for AA2024

Feed (mm/rev)	Speed (m/s)		
	0.72	1.42	2.83
0.05	0.530–0.305	0.660–0.395	0.743–0.408
0.10	0.655–0.285	1.050–0.828	0.948–0.550
0.30	3.150–2.700	3.760–3.440	3.195–3.040

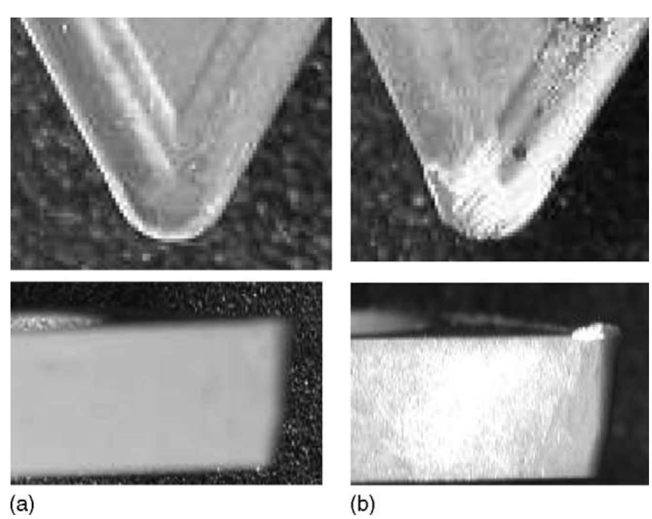

Fig. 11. Tools macrographs used during the machining process of: (a) AA7050; (b) AA2024, under the same cutting conditions.

Coming back to BUL and BUE, it must be remarked than the apparition of both incorporations causes an alteration in the initial tool geometry that affects to the surface finish quality of the pieces. The most influential factor is the change produced in the edge geometry [4,19].

According to [4,9], an expression of the *arithmetical average roughness* parameter, R_a, as a function of height of the peaks, h, left by the tool on the workpiece surface after the machining process was proposed.

Concretely, the function can be written as:

$$R_a = \frac{h}{3} \tag{2}$$

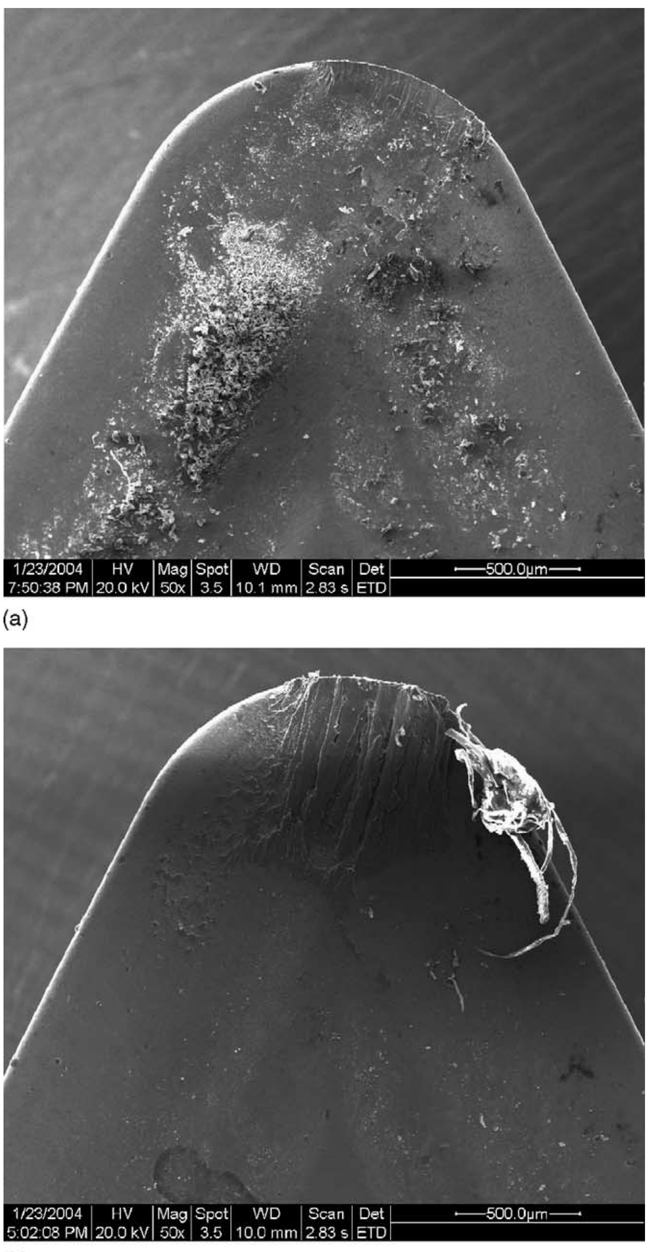

Fig. 12. Micrographs of the used tools during the machining process of: (a) AA7050; (b) AA2024, under the same cutting conditions.

Once tools and cutting conditions are selected and the parameters, such as the angle between the piece and the tool, χ and feed value, a, are known, the comes given by:

$$R_a = \frac{a}{6} tg\chi \tag{3}$$

Notice that this equation mark the direct influence of feed as it was above commented. Seeing previous graphs collected in Figs. 5 and 6, it is possible to conclude that R_a diminution happens in a staggered manner. R_a slight rises seem to indicate that, the material is adhered, it growths, it is plastically extended and, even, it can be mechanically removed during the process [14,19], in a cyclical way. Concretely, the adhered material is extended over the insert or removed from the tool in the valley-peak sections and then, the tool recovers, in a way, its initial geometry or other geometry close to it. In the peak-valley sections, the material either growths or is adhered again; this produces a slight improvement of the surface quality of the pieces in those sections.

This can be seen clearly in Fig. 10 where the case $a = 0.10$ mm/rev and $v = 1.42\,\mathrm{m/s}$ ($v = 85\,\mathrm{m/s}$) has been plotted.

In Table 3, it is presented the range of R_a values which will be obtained for each pair of cutting speed-feed values whenever AA7050 aluminium test-pieces of a 170 mm length are mechanized with a 2 mm depth. Seeing the data collected in Table 3, it is possible to affirm that, in the horizontal turning of AA7050 aluminium, the R_a value increases slightly with the cutting speed and more strongly with the feed as it could be expected from Eqs. (1) and (2).

A comparison between the values of R_a obtained working on AA7050 and those obtained in the same conditions on AA2024, Table 4, has been carried out. From this comparison, it can be said that, in these last case, they are smaller than in the first one.

This means that during the machining process of AA2024 higher amounts of material is adhered to the tool than in the AA7050 case, Figs. 11 and 12. This makes that the material peaks left on the surface of the pieces by the tool are softened.

5. Conclusions

R_a value of AA7050 aluminium pieces obtained by turning process has certain tendency to decrease with the machined length. Within this general tendency, R_a values increase slightly with the cutting speed and more strongly with the feed.

These phenomena can be explained taking into account that part of the machined material is adhered to the tool on the edge (BUE) and on the rake face (BUL) during the cutting process.

In the beginning of the process BUL is formed by a combination of thermal and mechanical causes. When BUL is just formed, BUE begin to be developed and is growing to a critical thickness. Once reached this thickness, BUE is mechanically extended onto the rake face of the tool increasing the thickness of BUL and forming a multiplayer.

The apparition of both incorporations causes an alteration in the initial tool geometry that affects to the surface finish quality of the pieces. The height of the roughness peaks diminishes as the material accumulation increases. R_a diminution takes places in a staggered form.

R_a slight rises seem to indicate that, the material is adhered, it growths, it is plastically extended and, even, it can be mechanically removed during the process, in a cyclical way.

Concretely, the adhered material is extended over the insert or removed from the tool in the valley-peak sections and then, the tool recovers, in a way, its initial geometry or other geometry close to it. In the peak-valley sections, the material either growths or is adhered again; this produces a slight improvement of the surface quality of the pieces in those sections.

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