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A SEM and EDS insight into the BUL and BUE differences in the turning processes of AA2024 Al–Cu alloy

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Abstract

When a Built-Up Edge (BUE) and a Built-Up Layer (BUL) are formed on the rake face of a tool, the surface finishing of the workpiece, the tool geometry and other output parameters can be affected. Till a few years ago both effects were considered as two forms of the same phenomenon. More recently, some authors have established differences between BUL and BUE, those related to thickness. The mechanism of BUL and BUE formation is not taken into account by these authors. This work reports on the results of a study using the SEM and EDS of the microstructural features of BUL and BUE formed over TiN turning inserts in machining of an Al–Cu alloy. The results obtained in this study have allowed the establishment of a first hypothesis about the differences between the mechanisms of BUL and BUE formation.

Keywords: Built-up edge; Built-up layer; BUL–BUE; Turning; AA2024

1. Introduction

In machining processes, tool life is usually determined using criteria based on tool wear [1]. Fig. 1 shows the intensity of tool wear, δ, as a function of cutting temperature, T, for different wear mechanisms [2]. Looking at this figure, it can be observed that the wear mechanism that operates in the widest range of cutting temperatures is the adhesion mechanism. Generally, adhesion wear involves the direct transfer of tool particles to the metallic chips [3]. However, tool wear may take place also by the incorporation of macroscopic fragments from the workpiece material to the tool surface [2–4]. These fragments are mechanically unstable and, thus, they can be removed from the tool surface by the action of the high strength cutting forces that are produced. In this process, tool particles are snatched giving rise to tool wear [2–4]. The workpiece material adheres on the rake face of the tool in two different, and almost simultaneous, forms, Fig. 2. The first one is the most known and it involves the formation of a Built-up Edge (BUE) by adhesion of the workpiece material to the cutting edge of the tool [2,5], Fig. 2(a). In the second one, the material transferred is poured to wider areas on the rake face of the tool, giving rise to the so-called Built-up Layer (BUL) [3,5,6], Fig. 2(b).

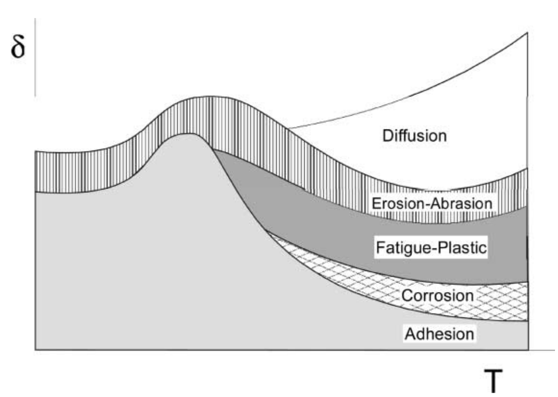

Fig. 1. Wear mechanisms as a function of temperature.

Up to the present, there are not many experimental evidences that allow us to decide which of such processes is operating under specific cutting conditions. Moreover, there are some controversies about the existence of differences between the mechanism of formation

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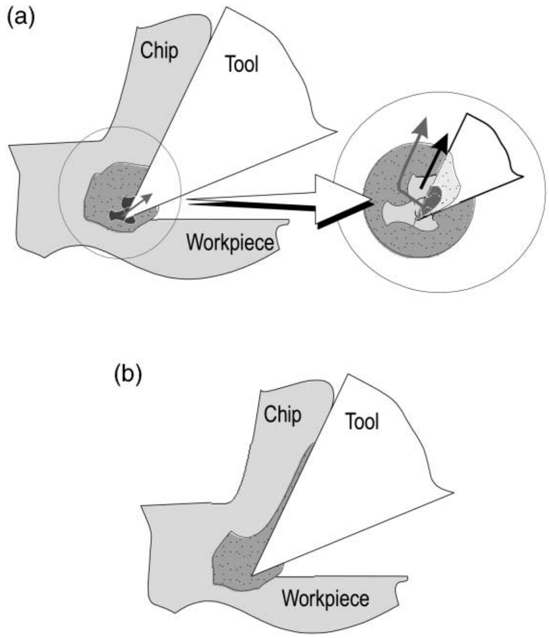

Fig. 2. (a) BUE formation mechanism and wear by adhesion. (b) Tool with BUE and BUL.

of both effects [7–9]. In this work, SEM and EDS have been used to identify the microstructural differences between the BUL and BUE regions formed during the cutting process of AA2024 Al–Cu alloy.

2. Experimental

Cylindrical bars of AA2024 (Al–4%Cu) in the T-351 temper state have been used as workpieces in the cutting experiments. This metallic alloy has a strategic importance in the aerospatial industry and the present study is part of a common project between our research group and the Spanish aeronautical company, Construcciones Aeronáuticas SA.

Prior to carrying out the cutting tests, the samples were rough dressed in order to remove the layers derived from the previous manufacturing processes, as well as the natural one formed by the exposure to its environment. Moreover, as recommended in Refs. [10–12], a further surface finishing process was achieved in order to avoid chattering effects.

Ten seconds cylindrical turning tests were achieved on a horizontal lathe, EmcoTurn 242 TC model, equipped with a Numerical Control Emcotronic TM02 with a 2(1/2) axis. The machining processes were performed using a cutting speed between 40 and 170 m/min, a feed between 0.05 and 0.3 mm/rev and a cutting depth of 2 mm. In agreement with Ref. [13], the cutting depth can be fixed in this kind of tests. The tools employed were ISO KCMW 11T3 08 FN M-SECO turning inserts,

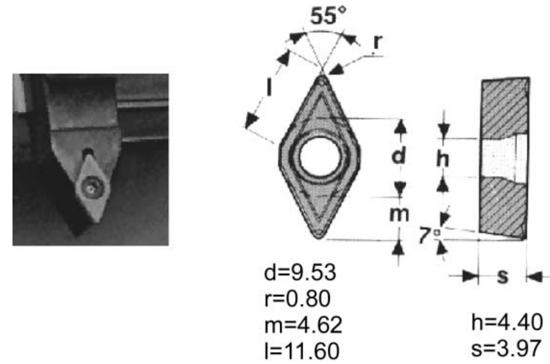

Fig. 3. Tool insert employed in the experimental study.

Fig. 3. Most of the tests achieved were repeated at least twice in order to guarantee its reproducibility. Finally, after each turning test, the tools were further observed in a JEOL-820 SM scanning microscope equipped with an AN-10000 LINK EDS spectrometer.

3. Results and discussions

Fig. 4 shows the SEM image of a turning insert after a 10 s cutting process at 85 m/min and 0.1 mm/rev in an AA2024 sample. The transfer of material from the workpiece to the tool surface can be observed in this figure. In agreement with Ref. [5], two regions of transferred material can be distinguished. In the first one, the material is accumulated close to the tool edge (BUE), whereas, in the second, it is extended on the rake face of the tool (BUL).

A multi-layer deposition form of the workpiece material can be suggested by the SEM image of Fig. 4. However, the thickness (δ) does not decrease progressively in the chip flow direction, marked by an arrow from A to B in this figure. A single roughness analysis

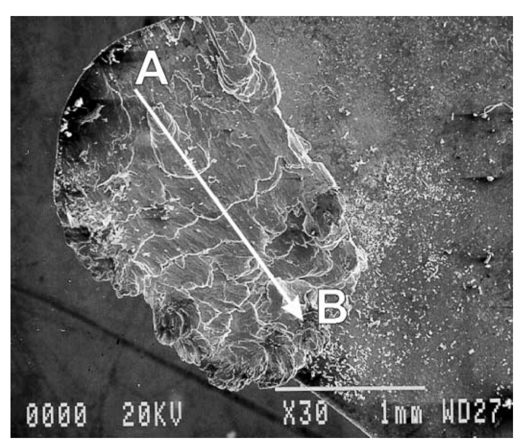

Fig. 4. SEM image acquired on a tool insert after 10 s turning test at 80 m/min.

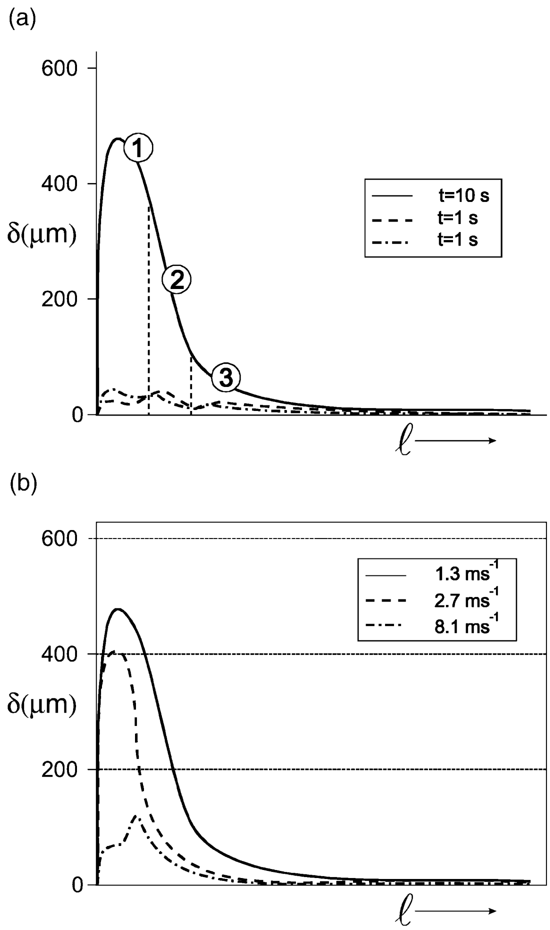

Fig. 5. Profiles recorded on the metal adhered onto the insert surfaces turned: (a) at 80 m/min during the indicated periods; (b) during 10 s at the indicated cutting speeds.

has been permitted to verify this fact. Fig. 5 shows the smoothed profile of the workpiece material accumulation in the AB (ℓ) direction for a sample turned 10 s at 80 m/min. Looking at this figure, a much higher metal accumulation in the nearest zones to the tool edge shows can be noticed, zone marked as (1). On the other hand, the zone marked by (2) shows a similar level of metal deposition. The intermediate zone, (3), is actually an interpolation of a stair distribution data. This fact can be explained as if the layering increase of thickness was stopped and a change in the mechanism seems to be produced. These results are in good agreement with those reported by Trent [5]. Thus, zone (1) can be related to BUE, zone (2) corresponds to BUL and zone (3) can be considered as a transition or ‘gap’ interval.

One second turning tests were performed in order to analyse the first stages of the metal workpiece accumulation. Fig. 6 shows the SEM image of the rake face of a tool employed in a one second test at 80 m/min. An initial metal accumulation associated to the BUL formation can be observed. The interpolated profiles recorded on two samples tested in these conditions are included in Fig. 5(a). This can be considered as an evidence that BUL formation is carried out in the initial stages of the cutting processes.

As it has been commented in the experimental paragraph, similar turning tests has been carried out at different cutting speed. The results obtained are in the same way as that discussed above. Notwithstanding, in agreement with the classical studies [7,14], a decrease of the BUE thickness when cutting speed increases can be observed, Fig. 5(b). A profile recorded on the accumulated material after a 500 m/min test is included. In a similar way a light decrease of the BUL thickness can be appreciated.

In agreement with the observations made in the above paragraph, the thickness differences point to different kinds of cutting effects onto the surface tool, in the opposite way to that proposed in Ref. [7]. SEM and EDS insights have been carried out on the tools after testing in order to extract further information about the differences between the BUL and BUE mechanisms of formation.

Fig. 7 shows a SEM image enlarging the boundary between the two regions assigned to BUL and BUE in Fig. 4.

EDS spectra were acquired in order to find compositional differences between BUL and BUE regions, Fig. 8(a) and (b), respectively. As a reference, the EDS spectrum corresponding to the alloy before machining has been included in Fig. 8(c).

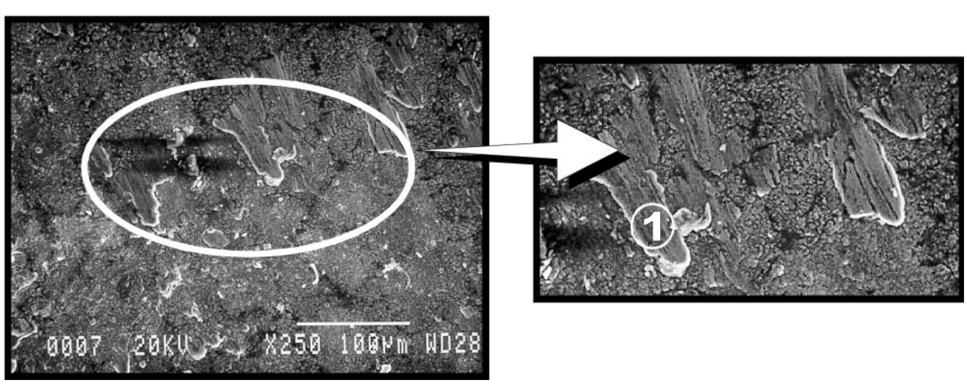

Fig. 6. Detail of BUL formed on the insert surface after a second turning test.

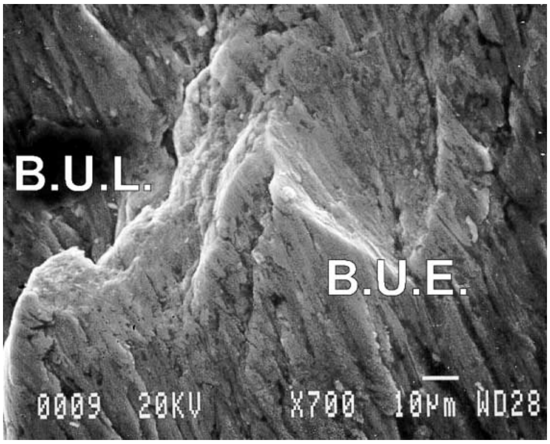

Fig. 7. SEM image acquired on the frontier between BUL and BUE.

From the comparison of these spectra it can be concluded that the intensities of the Fe and Cu peaks in the BUL, Fig. 8(a), are much lower than those observed for the same elements both in the BUE and the alloy, Fig. 8(b) and (c). Similar spectra have been found in the different cutting conditions analysed. This is a first evidence of the dissimilar nature of these two regions.

Fig. 9 reproduces an enlarged superposition of the spectra corresponding to those included in Fig. 8 in the Fe–Cu window. From this figure the compositional changes have been evaluated in terms of the percentage, P, of the decreasing sum of areas corresponding to the element characteristic peaks. Thus, in all cases, the percentage of reduction for BUE, P_{BUE}, has not been higher that 20%, and it has not shown any tendency with the cutting conditions imposed. A similar behaviour has shown this parameter for BUL, P_{BUL}, although, in this case, its value was always higher than 50%.

The compositional differences stated above could be related with a loss of (Al,Cu,Fe) intermetallic particles during the BUL growth. The high temperatures reached in the initial stages of the cutting process cause the incipient melting of Al matrix in the alloy, which flows on the rake face of the tool [6,13]. Under these conditions the metallic chips would drag off the solid intermetallic particles.

A similar situation has been proved in Refs. [15,16] when resulphurised steel enriched with calcium is machined. The Ca-rich intermetallics in the alloy have a lower melting point than the Fe matrix. Thus, in this case, these inclusions are responsible for the adherent layer formation.

Coming back to the AA2024 alloy, once the BUL is formed, the Al accumulated on the tool surface reduces its initial hardness. As a consequence of this process the temperature reached during the next steps of the cutting process decreases [3–7]. This avoids the melting of the alloy and the workpiece material. Due to this, this material will remain in the zones close to the edge for-

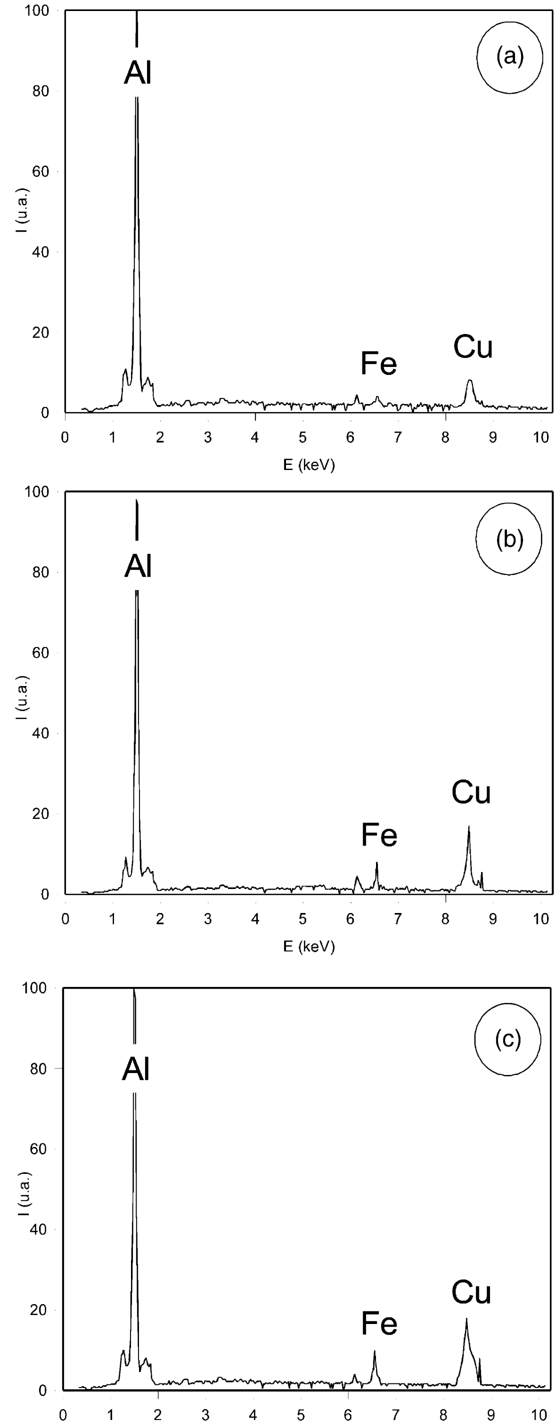

Fig. 8. EDS spectra recorded on: (a) BUL, (b) BUE and (c) alloy AA2024.

ming the BUE, which shows a composition close to that of the machined alloy.

4. Conclusions

When an Al–Cu alloy is turned into a moderate range of cutting speed, two kinds of material deposition onto

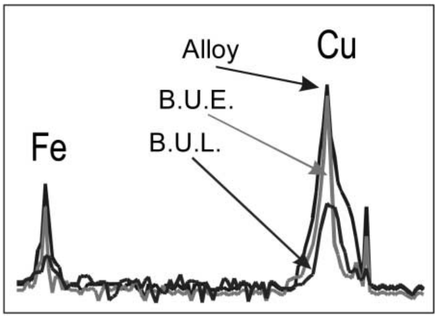

Fig. 9. Detail of the Fe and Cu peaks of the EDS spectra included in Fig. 8.

the tool rake face can be differentiated. In the first stages of the machining process, an aluminium based metallic layer is formed, giving rise to BUL. This can be associated to the initial melting of the metallic matrix followed by an extrusion process due to the compression forces between the chip and tool. The chip drags off the Al–Cu–Fe inclusions, which have a higher melting point. The SEM images and EDS spectra recorded onto the tool surface after different machining times supports this initial mechanism. The layer so-formed has lower hardness than the tool. Thereby, the cutting temperatures diminish. This fact causes a change in the material deposition mechanism onto the rake face of the tool. Thus, a classical theory based on the adhesion mechanism can be considered for the BUE formation. The SEM and EDS spectra recorded on these regions shows dissimilar thickness and composition between the BUL and BUE. So, BUE has a composition highly similar to the original alloy with much higher contents in Fe and Cu than those detected for BUL.

To sum up, evidences of the different mechanism that take place in the formation of BUE and BUL have been shown in Fig. 10.

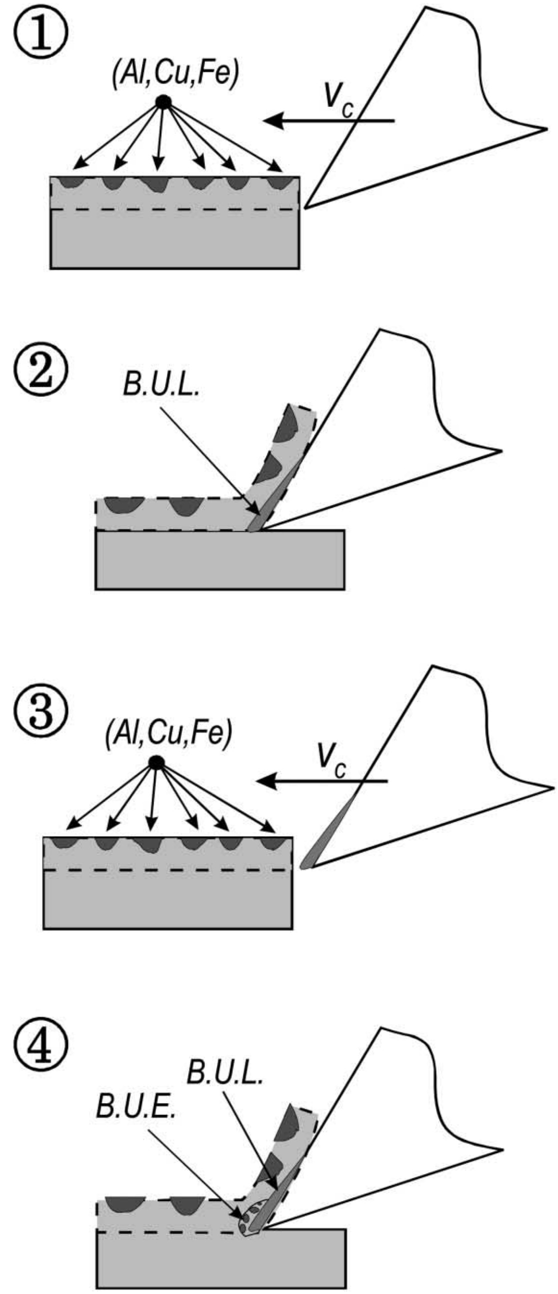

Fig. 10. Scheme of the BUL (a) and (b) and BUE (c) and (d) formation.

Acknowledgements

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