FVM based Methodology for Evaluating Adhesion Wear of Cutting Tools

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Abstract

In the machining processes, surface quality of the worked pieces depends strongly on the tool conditions. Tool wear has, by that, a determinant influence on the surface finishing quality of the machined products. Tool wear has been commonly associated with the loss of tool material. Standards, procedures and methodologies have been developed for evaluating tool wear under that idea. However, currently, the tool wear concept must be considered in a wider meaning. In effect, nowadays, tool wear must be related to the changes in the cutting tool caused by the machining process. These changes contain both its geometrical and physicochemical properties variations. The first of them involves not only the loss of material but also the incorporation of machined material to the cutting tool, as in the secondary adhesion wear, where workpiece material is adhered to the tool in two well-defined zones: rake face, giving rise to the Built-Up Layer (BUL); edge and clearance face, giving rise to the Built-Up Edge (BUE). Up to the present, the evaluation of BUL and BUE has not been satisfactorily solved and, by that, the secondary adhesion tool wear is hardly evaluated. Only some indirect methods can be found based in output variables and parameters (Cutting Forces, Surface Quality Parameters).

In this paper, a BUL and BUE measuring methodology, based in the reproduction of BUL-BUE 3D surfaces through Focus-Variation Microscopy, has been proposed. This methodology can serve as a first reference for standardizing the evaluation of secondary adhesion tool wear.

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1. Introduction

Currently, manufacturing processes require a higher efficiency ratio, especially significant considering the current economic situation.

Economical, Energetic, Environmental and Functional (E3F) requirements are increasingly demanded of means of production, either by legal limitations, or by higher technical exigencies [1-3]. Thus, manufacturing process performance cannot be only understood under economical considerations [3].

Applying this to the context of machining process, it is possible to find a lot of parameters and variables, which play very important roles in the E3F process efficiency. In particular, up to the present, tool life has a high relevance in the E3 performance of a machining process. On the other hand, tool wear is the main measurement to evaluate tool life [3], because it can influence on all the E3F requirements. Minimizing tool wear, it is possible to maximize tool life. However, it is necessary to know and to evaluate the tool wear mechanisms for that.

In the particular case of the Aluminium Alloys, secondary adhesion wear has been shown as the main tool wear mechanism [4-7]. This kind of wear affects directly to the workpiece surface quality and it can be found in two different forms and tool zones: a layer onto the tool rake face (Built-Up Layer, BUL); or a bulk placed in the tool edge or tool clearance (Built-Up Edge, BUE) [7].

In previous works, these mechanisms have been deeply characterized [7,8] and the BUL-BUE formation, nature and evolution have been determined. However, it
is not easy to find an evaluation of these effects based on direct measurements [9].

In effect, up to the present, BUL and BUE has been only estimated -not evaluated- by indirect measurements through other variables such as roughness, force, vibrations, temperature [3-8].

Latest trends in this field of investigation tends pursues non-contact measurement methods that can capture the quantity and distribution of material adhered, setting the groundwork for future standards on how to evaluate and classify the secondary adhesive wear [10].

In this paper an microscopy images based method has been used in order to evaluate the extension (area) and volume of the adhered material in the dry turning of an aerospace aluminum-copper alloy (UNS A9204). Dry machining was selected in order to increase the environmental performance, avoiding the use of lubricants that can affect negatively to environment.

2. Experimental Procedure

The first of the goals pursued in the present study, is to be able to extend its conclusions as general as possible, so those processes have been selected and means to facilitate this objective.

So, complex tool geometry and complex machining processes have been avoided. In this sense a horizontal turning process was selected and a neutral turning insert was employed.

2.1. Material

The material selected for the carry out the tests must respond to ductile performance present in the elaboration of light alloys parts employed in the aeronautical field. Thus, the selected alloy was one the widest used in the aerospace industry: UNS A9204 T3 (Al-Cu).

Table 1 includes the weight percent composition of this alloy.

Table 1. Nominal composition of aluminium alloy

| Designation: Aluminium Association 2024; UNS: A9204; ISO AlCu4Mg1 (% in mass) |
|---|---|---|---|---|---|---|---|---|---|---|
| Cu | Mg | Zn | Mn | Si | Fe | Ti | Cr | Others | Al |
| 3.8 | 1.2 | 0.25 | 0.3 | 0.50 | 0.50 | 0.15 | 0.10 | (*) | 4.9 | 0.9 | (***) |

(*) Specified: A(Zr+Ti) ≤ 0.20%;

(**) No Specified : 0.05 (partial) /0.15 total

2.2. Tools

Coated and uncoated interchangeable turning tools used for testing are developed by means of the powder synthesized tungsten carbide (WC) and cobalt (Co) manufactured by SECO. These insert tool are identified by the code ISO standardization DCMT 11T308-F2-HX (uncoated), and ISO DCMT 11T3308-F2-TP (CVD covered: Ti(C,N) and Al203 Duratomic TM).

Figure 1 shows the main geometric characteristics of such tools.

![Geometry and dimensions of the cutting tools used](image)

Fig. 1. Geometry and dimensions that define the cutting tools used

2.3. Machining Process

Horizontal turning tests were performed in the experimental stage of this work. Cutting fluids were avoided (dry turning) in order to increase the aggressiveness of the cutting process. On the other hand, environmental laws force to minimize the use of lubricants in order to apply clean technologies.

Dry turning tests were conducted in a CNC machining center EMCO-Turn 242, equipped with Numerical Control EMCO-Tronic TM02.

Test workpieces were dry turned applying cutting speeds (s) from 50 to 200 m / min, feed-rates (f) from 0.05 to 0.30 mm / rev and a constant cutting depth (d) of 1 mm. Short-time tests (1 to 10 s) were achieved in order to block the first stages of the tool adhesion wear.

2.4. BUL-BUE Measurements

The measurement stage has been made using the new family of optical inspection equipments, thanks to which it has been possible to capture information without needing a direct contact with stylus.

One of the most relevant non-contact measurements next generation is that based on the “variation of focus” in a microscope. This is a single technique consisting on a variable approach in different planes, capturing all the
data needed to generate 3D models measured on the surface variations.

Figure 2 includes an image of the equipment used for this study, an ALICONA G4e InfiniteFocus-IFM microscope.

This technique has been applied on three zones (AREAS) of the cutting tool, Figure 3: cutting edge (area 1); tool end nose (area 2); and auxiliary cutting edge (area 3).

![Fig. 2. ALICONA G4e InfiniteFocus-IFM Microscope](image)

Flow-diagram included in Figure 4 shows the different phases of development of this work.

### 3. Measurement considerations

The evaluation of the areas of study has been conducted comparing the surface 3D models before and after the performance of the tests. From this comparison, the changes of material amounts on the areas of influence were determined.

In a first phase, it has been necessary to define the measurement tool areas, which can contain different wear adhesion information and repercussion on the surface quality of the workpiece. One the criteria to select these areas is based on the trajectory and displacement of the chip across the rake face. All these considerations can be used to take advantage for standardizing this comparison model.

The main area of study is dividing according the individual repercussion on the tool wear or the king of secondary adhesion wear that can be identified on it. These areas have a direct influence on the surface quality of the workpieces -once BUL and/or BUE are formed- and also on the chip formation and development.

As it has been aforementioned, these areas are placed in Figure 3.

![Fig. 3. Defined areas on the insert tool for evaluating adhesion wear.](image)

The comparison of 3D models of each tool in the states before and after the test, the study gives greater information veracity wanted, since the possible variations detected are caused only to the machining process itself, and not others factors such as the differences between their own tools resulting from fabrication tolerances.

A clear view of the material stuck to the tool is achieved after obtaining the differences of 3D models, clearly highlighting distribution rake face and cutting edge. Now it can be start making hypothesis about the behavior.

Through the use of other processing software, 3D models have been developed for a second study -more rigorous form the metrological viewpoint- for determining the location, area and real volume of material adhered.

At this stage other related analyzes these data can be developed. Thus, the trajectory of the chip through the rake face can be the rebuild.

### 4. Results and Discussion

The results obtained by this new evaluation methodology provides a clear visualization of the modified areas during the tests, allowing visual analysis relating the material adhered areas and its relationship to the technological parameters of the machining process and the type of tool used.

Comparative 3D models have been studied more deeply through several processing software modeling surface profile metrology, obtaining a parallel information concerning the material adhered to the tool. This has been selected for a family of parallel trajectories placed from the cutting edge and perpendicularly oriented to it.

It can allow obtaining the profiles that characterize the different areas of interest.
Fig. 4. Activities conducted for capturing 3D models and their both differentiation and analysis
Figure 5 includes a processed image of the 3D model generated after this comparative process.

Defined areas that have been a greater modification have been related to the technological parameters applied in the dry turning tests. The main bulk differences and profile height have been considered as reminiscent adhesion material.

Figure 6 shows a first evaluation of the treatment of above discussed data. This evaluation is presented for one profile -as the height of profile as a difference with the original tool- and it can be seen the adhered material variation by type of test and studied areas.

Looking at this figure, it can be appreciated as the distribution of points with greater level on each of the acquired profiles, displayed a greater elevation of material on the cutting edge, which descends steeply to the middle zone, area 2, which remains constant for then back down drastically. According to [3,7,8], area 1 can be identified as BUE, area 2 as secondary BUL and area 3 as primary BUL.

Figure 7 shows the second analysis proposed by this methodology. If in this case shown in Figure 6 considers the greater elevation of each profile, related in place of the profile over the area of interest of the tool.

In this second case the object of study is the highest point of each profile, related to the distance of this about the line perpendicular to the cutting edge and tangent to the cutting tip. Through such studies can be analyzed the fluctuation of material in relation to the perpendicularity of the cut. This can be associated with the changes with the edge and the perpendicular to it. Thus, thermal changes and chip-workpiece plastic strains can be related to it, as it is appointed in [3,7,8]

5. Conclusions

The first evaluations presented uncoated tools with a higher proportion of material adhered, with defined points, higher and steep.

On the other hand, a relation between cutting speed and the level of dispersion of material adhered on the rake face has been detected.

The displacement of material stuck in uncoated tools is notable in connection with increasing cutting speed, showing stable in the same areas to uncoated tools. Thermal effects are more intense in coated tools and BUL-BUE effects are also higher.

Thanks to the kind of analysis of the data shown in this work, it is possible study the geometric changes undergone in the different zones of influence of the tool on the workpiece.

![Adhered Material by profile](image)
Additional studies of material adhered may complete this information, plus an added material distribution, physicochemical nature, sitting and the basis for evaluation and study of tool wear secondary adhesion.

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