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# Wear Behavior of the Pair Superalloy FXS-414 and Cutting Tool-Carbide Coated TiN

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***Abstract*-The machining of superalloy parts remains a dark area in mechanical manufacturing. It is limited in particular areas such as gas turbines, rocket engines, space vessels, nuclear reactors and pumps. Friction theory still seems to be in arrears with respect to the practice, although friction is implicated in many scientific disciplines. Industrials have been interested for many years in the development and characterization of materials in order to provide wear-resistant mechanical parts. In this context, study of the tribological behaviour of the cobalt based superalloy FXS-414 standard 9001F against the metallic carbide coated inserts TiN provides important information in the case of the turbine blades industry. The three main mechanisms responsible for the wear of the cutting tools are adhesion, abrasion and diffusion. The life of the cutting tool is primarily related to the development of two types of wear: flank wear and crater wear. This wear phenomenon appears to be scalable. It is developed during cutting, which impairs the quality of machining and the productivity, and it may even lead to the destruction of the tool in the case of excessive wear.**

**The durability of machine tools often depends on tribological characteristics of the couple cutting tool material / workpiece. The characterization of superalloys is late compared to other materials. The choice of the cutting tool for machining superalloys is not really invested because of the high cost of machining means. It has been shown that the coating is the most influential parameter, followed by the sliding velocity and feed rate.**

***Keywords- Cutting Speed; Crater Wear; Drilling; Flank Wear; Friction; Tribology; Wear***

## I. INTRODUCTION

Several methods of controlling the wear of cutting tools have been applied to satisfy productivity needs. Using indirect techniques, describing the roughness of the piece enables one to explore the different resulting types of machining such as signals, cutting forces, acoustic emission and vibration in order to extract the information needed to carry out an effective control [1]. In the same way, other indirect methods are simultaneously used to follow the evolution of the wear during machining. The following context, contributes to the study of a method of monitoring the cutting tool, which consists of measuring the tool wear by a binocular microscope directly on the plate of the tool, after machining tests at different milling operations. For a long time, the tribological factors related to machining behaviour of materials pairs tool / workpiece materials deeply affected the operation and maintenance service mechanisms and the proper execution of their function as guidance systems, sealing and quality manufacturing [2]. They are always measurable on a small scale, and it is necessary to describe them adequately since their description does not date only from yesterday [3, 4]. This tribological wear phenomenon appears to be scalable and develops during cutting, which affects the quality of machining and the productivity particularly, it may lead to the destruction of the tool in the case of excessive wear [5]. For these reasons, the careful selection of cutting parameters is necessary, even essential, for successful productivity. The tribometer designed to follow the progress of the friction coefficient does not offer concrete results from wear and shape, particularly during a sudden tool failure [6]. The image carries more information on this subject and the interpretation is more straightforward. Measuring the sizes with better software allows one to provide very high accuracy. The wear of cutting tools can occur through erosion, abrasion, adhesion and diffusion [7, 8]. Such problems, essentially of tribological nature, vary considerably from one family to another family of steels. Material characterization is essential in developing new products of steels [9-11].

Due to the low machinability of the alloy under study, selecting the machining conditions and parameters is crucial [12]. In addition, wear tests indicated that the signature of the wear on the wall was different from one geometry to the other. Several authors have shown that the damage of the tool is strongly affected by the feed rate, the material and geometry of the tool, the wear rate of the tool and the quality of the interface compound material [13, 14].

This work falls within the research framework for optimizing cutting times TiN coated pellets which will be followed by other AlTiCN, Ti2CN, TiC, AlTiN or using multilayer coatings; to make the choice to perform mass production.

## II. EXPERIMENTAL PROCEDURE

The objective of this work is to create a real wear using ten identical TiN coated pellets after two milling operations using constant cutting parameters but varying the cutting time. Next, one measures the flank wear and then compares the results. The superalloy used in this study contains cobalt as a main element, commercially known as FXS-414 with an average hardness of 60 HRC; the chemical composition is given in the following Table 1.

TABLE 1 CHEMICAL COMPOSITION OF THE SUPERALLOY FXS-414 (WEIGHT %.)

| Co | Cr | Ni | W | Fe | C | B |
|---|---|---|---|---|---|---|
| 52 | 29 | 10 | 7,5 | 1 | 0,25 | 0,010 |

The tests have been carried out on a 5-axis machining center DMG MORI DMF model 180 (Fig. 1), using a cutting tool coated head R217 / 220.29-6 type on 5 cylindrical carbide inserts coated with titanium nitride (TiN) by PVD process (RPHT1204M0T-M08 reference F40M) achieving a layer of 5 microns thickness (Fig. 2).

The cutting conditions are as follows:

Rotation speed n = 400 r / min, Vc = 150m/min; Fz = 0.075 mm / tooth;

Depth of cut = 0.5 mm. The first operation is an inclined face surfacing 45 °(Fig. 3);

Number of passes: 16, Machining time: 30 min.

Fig. 1 DFM180 Machine (Vertical Machining Center 5 axes)

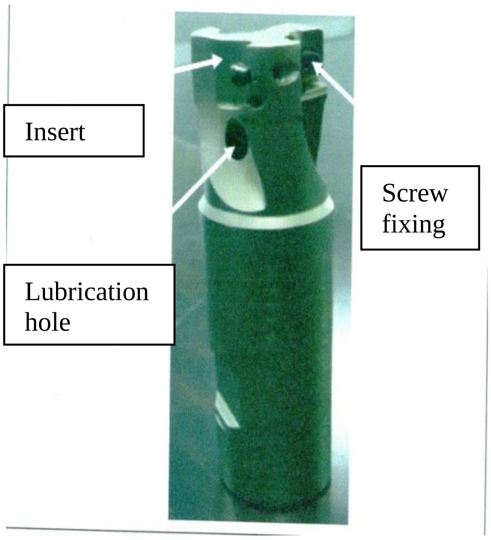


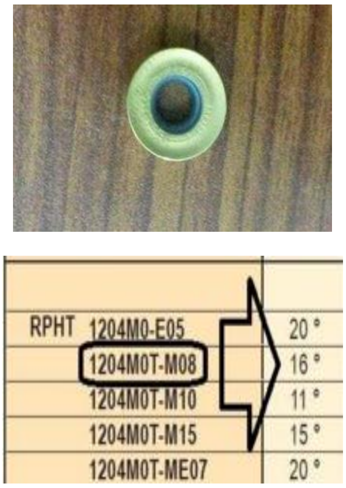

Fig. 2 Movable cutter pellets

The second operation is a straight face milling (Fig. 4). In this case, the number of passes is equal to 18, the machining time is fixed to 60 min.

Fig. 3 Face milling operation of the inclined face

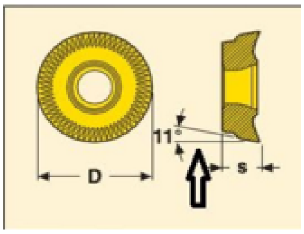
Fig. 4 The straight face milling operation

According to the manufacturer SECO, the insert used has a draft angle of 16 ° as shown in Fig. 5c. The cutting position is changed twice on the same insert: one for the first operation and the other for the second operation. This is done on two identical pieces in order to remove the same quantity of material for each machined face.




A- As received insert

B- Worn insert




C- The draft angle according to the manufacturer SECO

Fig. 5 The insert used in the tests

For the measurement of wear, a direct technique has been adopted, using an optical binocular microscope (Euromex). The zoom magnification is twice the actual size. It is equipped with a Phonotic Touptek camera coupled to a software capture and Toupview image analysis to measure the  wear of the cutting plates as shown in Fig. 6.

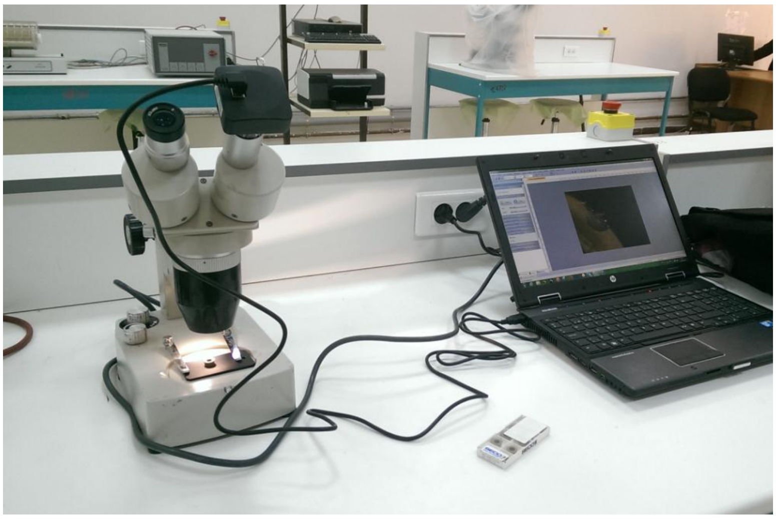
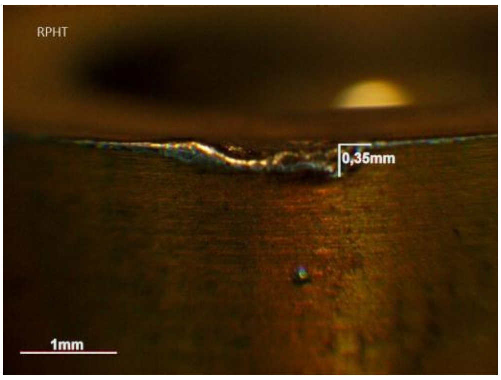


Fig. 6 Binocular microscope and Toupview software used to determine the wear acquisition interface of the insert

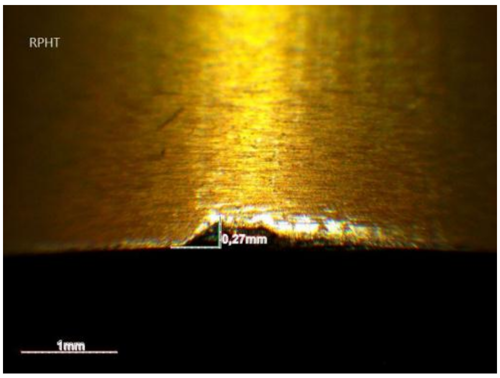
## III. RESULTS AND DISCUSSION

Evolution of wear as a function of time:

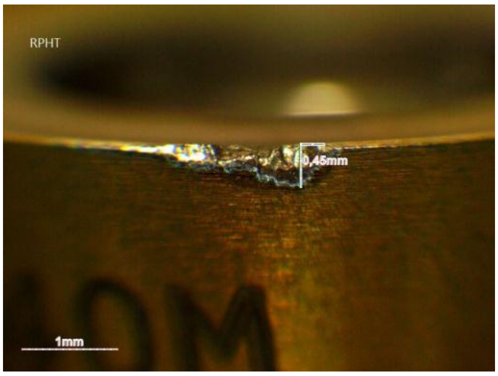
Fig. 7 provides an overview of the flank wear of the pellets coated with TiN. It’s noticed that there are significant differences in the material removal (0.27mm and 0.45mm) for the same period of friction, which is fixed at 30 minutes.



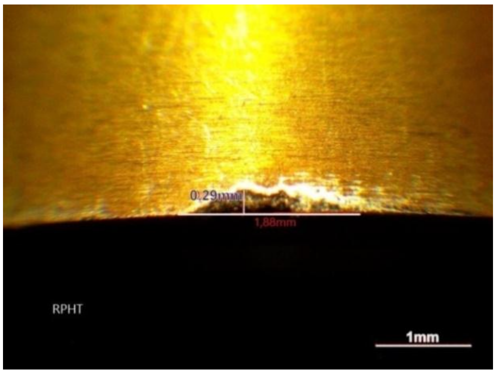

1. Flank wear for $V_B$ = 0.35mm (x20)



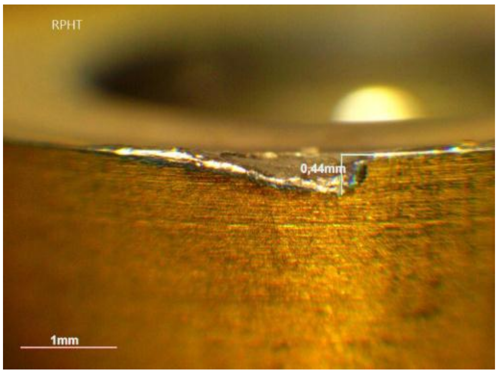

2. Flank wear for $V_B$ = 0.27 mm (x20)



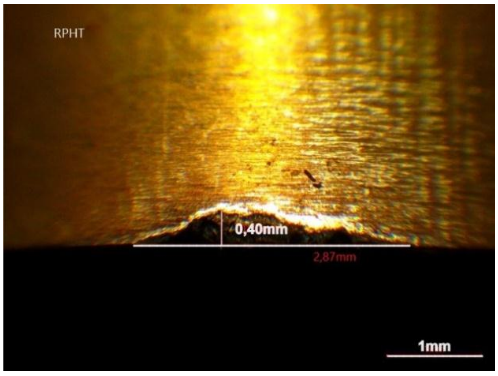

3. $V_B$=0.45mm (x20)



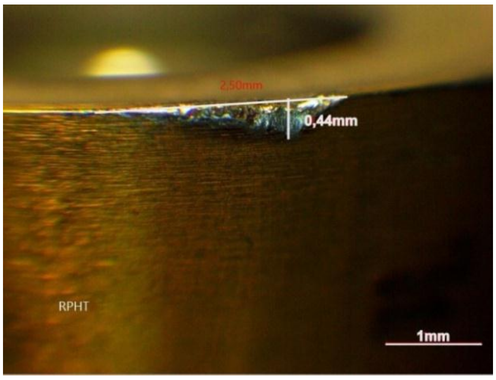

4. $V_B$=0.29mm (x20)



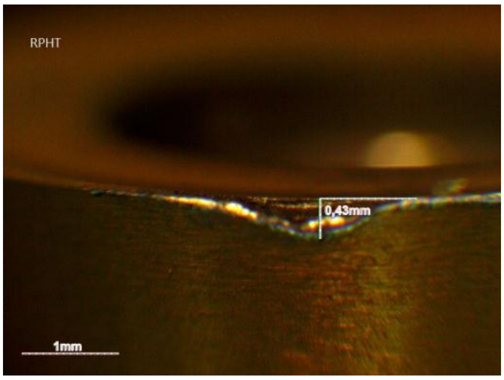

5. $V_B$=0.44mm (x20)




6. $V_B$=0. 40mm (x20)



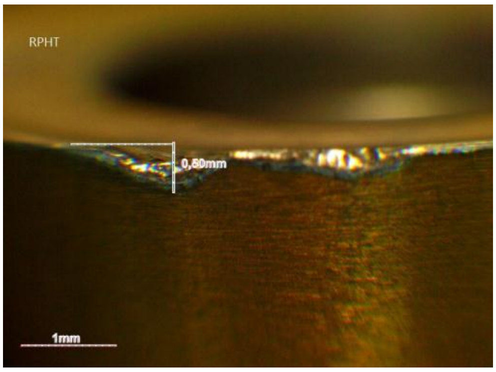

7. $V_B$=0.44mm (x20)



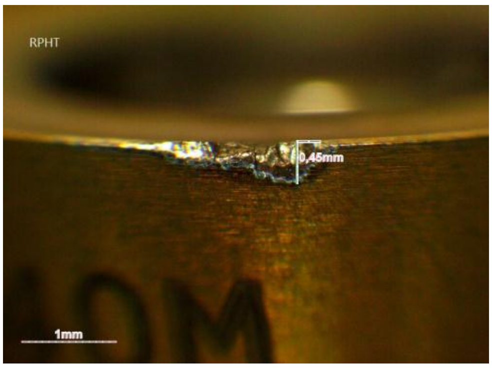

8. $V_B$=0.43mm (x20)

Fig. 7 Results of the first test measurements for the same period of friction fixed at 30 minutes

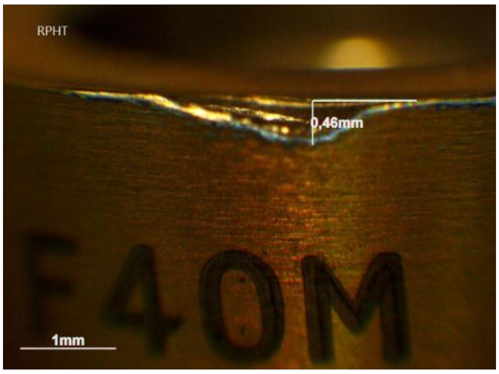
In the case of the second test series where the friction period time is fixed at 60 minutes (Fig. 8), the differences in the material removal are not significant compared to the first test series. The flank and crater wear are more noticeable. They sometimes reach the value allowed by ISO 3615 ($V_B$ = 0.6mm) to the roughing.



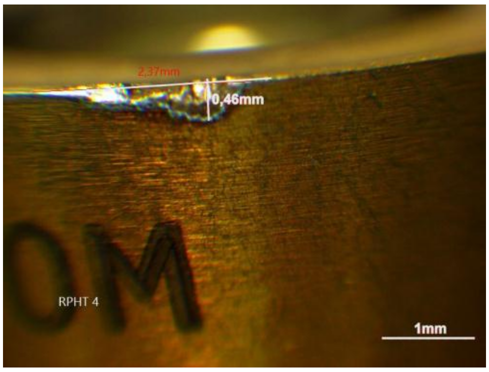

1. $V_B$=0.50mm (x20)



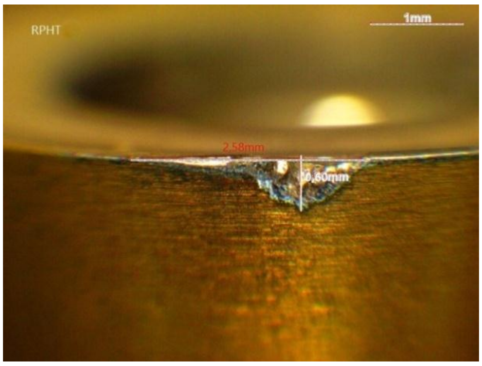

2. $V_B$=0.45mm (x20)



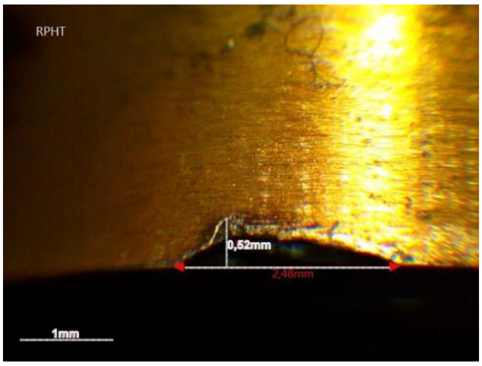

3. $V_B$=0.46mm (x20)



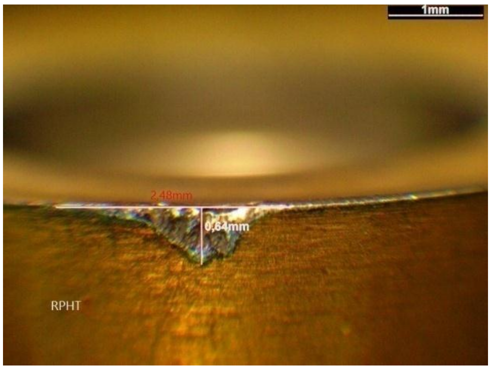

4. $V_B$=0.46mm (x20)



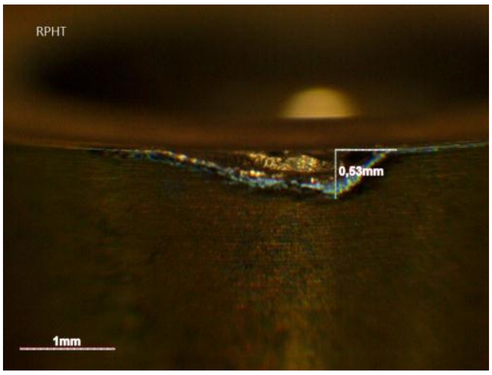

5. $V_B$=0.60mm (x20)




6. $V_B$=0.52mm (x20)




7. $V_B$=0.64mm (x20)




8. $V_B$=0.53mm (x20)

Fig. 8 Results of the second test measurements for the same period of friction fixed at 60 minutes

In this case, the tool must be changed; otherwise, the surface quality will get worse. On the basis of the curves in Fig. 9, it is well noticed that the maximum difference in the flank and crater wear is 0.18 mm for the same cutting conditions. One can therefore say that wear is never regular, and there are other parameters that are involved in the tribological system.

After having calculated the average measurement of wear for both cases, the following values can be found:

$$V_{B(30min)} = 0.377 \approx 0.38mm;\ V_{B(60min)} = 0.526 \approx 0.53mm.$$

Fig. 9 shows the wear distribution $V_B$ of ten inserts. One can see that there is a small wear dispersion of wear measured for the 10 inserts, which is about 9.4%. This value has been calculated using the following formula:

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_m)^2}{n-1}}$$. The coefficient of variation is $CV = \frac{S}{x_m}$ %.

where $x_i$ = measured value; $x_m$ = average value; n= number of measured values.

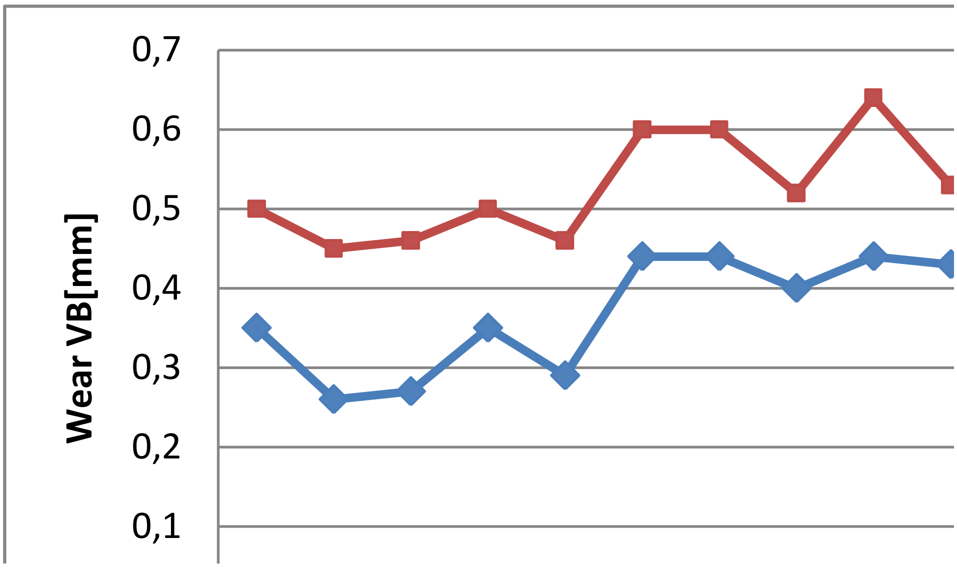



Fig. 9 Wear distribution $V_B$ of inserts

This dispersion is due to the high hardness of the material being machined and tribological phenomena generated by its properties, which causes a machining difficulty. One notices that there are vibrations at the machine despite its rigidity and strength, and with respect to the dispersion of the measured wear values of inserts as a function of time (30 min and 60 min).

In the case of calculating the wear average, one can determine the change in the flank wear rate $V_B$ within 30 minutes for a growth rate equal to 40%, which enables interpolation of wear for other time values.

Fig. 10 shows the evolution of wear $V_B$ and $K_T$ as a function of time by the interpolation of the results of measurements.

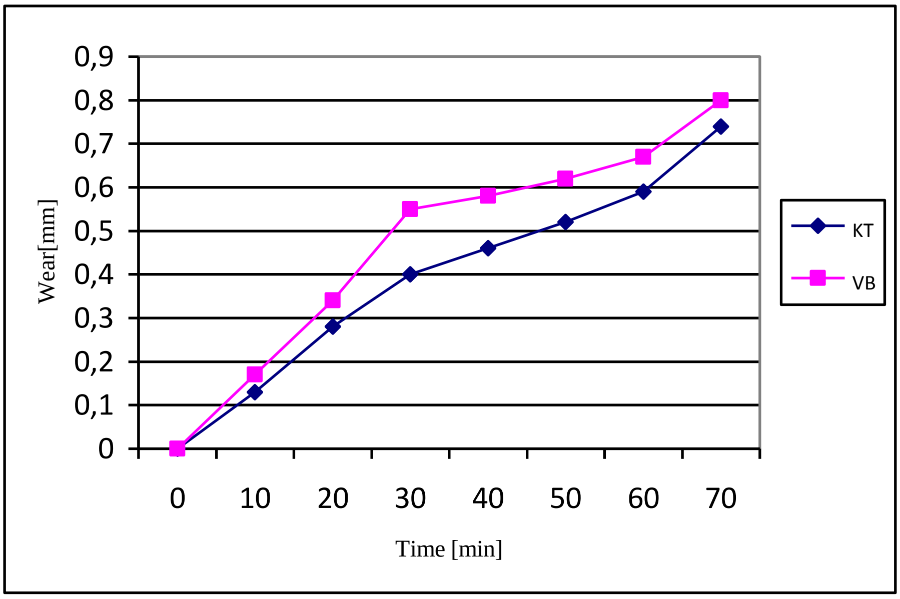



Fig. 10 Evolution of wear $V_B$ and $K_T$ as a function of time

The curves show the evolution of the $V_B$ and $K_T$ flank wear as a function of time in the case of machining a superalloy FXS-414 Cobalt-based. In our case, the practical part shows three phases in determining the lifetime of the cutting insert: milling, maturity and accelerated wear.

1. Milling (0-30 min): It can be observed that there is a noticeable and continuous increase in flank and crater wear of the insert as function of time, which reaches a value of $V_B$ = 0.38 mm (critical value for a finish machining), so the insert wears very rapidly during this period.

2. Maturity (30-60 min): There is a steady increase in flank and crater wear ($V_B$, $K_T$) as a function of time with a growth rate equal to 40% (between 0.38 and 0.53 mm) for 30 and 60 min. This represents the wear of the cutting tool in the stabilization phase VB until it reaches a value less than 0.6 mm (critical value agreed by the AFNOR 3615 for roughing machining).

3. Accelerated wear: for more than or equal to 60 minutes: The accelerated wear phase of cutting tool after fracture. During this period, there is a gradual increase in abrupt failure of the cutting edge, and this will lead to the end of the lifetime of the insert.

It is noticed that the three lifetime phases of the tested insets have an excessive increase in flank wear $V_B$ as a function of time and a high growth rate compared to standard norms. This might be due to the high hardness and difficult machinability of the AISI 310 material being machined which has a high mechanical tensile strength (more than 1000 MPa) despite the ideal choice of the cutting insert.

## IV. CONCLUSION

This work allowed one to understand the science of tribology and friction phenomena occurring when the specimen and the tool- are in contact, thus causing wear of the cutting tool.

Many parameters can influence the wear of cutting tools such as the couple: tool material / material to be machined. The toughness of this type of material requires very specific cutting parameters, such as reducing the depth of cut and a well defined feed rate that is (Fz = 0.075 mm / tooth).

Despite its high hardness and high mechanical tensile strength (> 1000 MPa), the wear behaviour of the cutting plate used in machining is not well defined for other cutting parameters of the antagonist material. Although it is robust, the instability of the milling machine will result in the sudden breaking and the rapid flaking of the beak of the tool.

We can conclude that this tool cannot ensure good quality of the machined surface after 60 minutes. This damage is more pronounced during the machining of composite and stainless metal structures (sandwich) during assembly.

Flank wear is the primary tool wear mechanism that develops during machining of stainless steel materials. This flank wear is due to the high abradability of the austenitic grains, which rub against the flank face of the tool.

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