Indirect monitoring method of tool wear using the analysis of cutting force during dry machining of Ti alloys

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ABSTRACT

In recent decades, optimize tool life is in constant evolution so many researchers have focused to analysis the tool wear by indirect monitoring (e.g. acoustic emission, cutting forces, vibrations) that plays a significant role in control and improvement of product during of machining operations - in real time to prevent instabilities of process [1-4].

On another hand, it is recalled that titanium alloys are used in many industries as aerospace sector that have been utilized in strength to weight ration reduction in some parts of aircraft. On the negative side, Ti alloys tends to be hard machining due to their mechanical properties such as low thermal conductivity and modulus of elasticity causing increase cutting temperature, tool breakage or possibility interruption of process.

Keywords: Titanium alloys, Orthogonal cutting, Cutting force, Chip morphology and Wear mechanisms.

1. Introduction

Nowadays, cost saving and productivity improvements problems are becoming a serious threat to the survival and development of manufacturing industries. In this investigation consists to understanding aerospace manufacturing process to particularly on those involve metal cutting operations by removal of material which results in chips formation. Recent trends are in focus to understanding the mechanisms of chip formation and improves several methods to develop monitoring devices for detect the first wear levels on the cutting tool, in this case the principal goal is to be offer a cost-effective route to improve economic [3, 5].

At the same time in this manufacturing sector (aerospace) working with machining difficult-to-machine materials or hard-to-cut materials, the area of these types of materials and their properties are not clear yet. Some materials such as titanium based alloys are usually accompanied with low productivity, poor surface quality and short tool life. Ti alloys are materials of choice because have high strength and low density make them suitable for aircraft parts [6].

For these reasons, this paper present have intention to understanding of chips formations by geometrical and metallurgical characteristics because is part of the performance of the cutting process; in this case by turning process. And another hand to identify the wear mechanisms into cutting tool associated into machining titanium based alloys.

2. Methodology Experimental

This investigation focused into understanding by empirical analysis for tool wear monitoring in machining of *Ti6Al4V* alloy using geometry orthogonal cutting into flexible workpiece.

2.1 <u>Material and cutting parameters</u>

This experimental study was designed to evaluate behavior of material *Ti6Al4V* with chemical composition shown in Table I, during cutting process to determine the main influence on the chip morphology under certain conditions generated on the first stage of machining.

Table I. *Chemical composition of Ti6Al4V* alloy *(wt%).*

Ti6Al4V	**C**	**Fe**	**N**	**O**	**Al**	**V**	**Ti**
Piece	1,89	0,164	0,05	0,05	5,47	4,09	Rest
Standard	0,08	0,25	0,05	0,02	5,5-6,76	3,5-4,5	Rest

Experimental work was conducted in order to study the effect of cutting parameters. In particular with feed rate, *f*, cutting speed, V_c and keeping constant the variable like cutting depth, *ap*. For this experiments has been employed these cutting parameters, see Table II.

Table II. *Cutting Parameters.*

Cutting Parameters	**Ranges**			
f [mm/r]	0,05	0,1	0,2	0,3
V_c [mm/min]	65	80	100	
ap [mm]	1			

2.2 Design of workpiece

The cutting experiments a device was specially developed to reproduce the chip geometry side flow during dry turning test by geometry orthogonal conditions using as flexible workpiece such as a tube (cylindrical bar), see Figure 1. The significant of this design was selected for two reasons: to achieve different ranges of cutting speed, feed rate and to the other hand to produce orthogonal cutting.

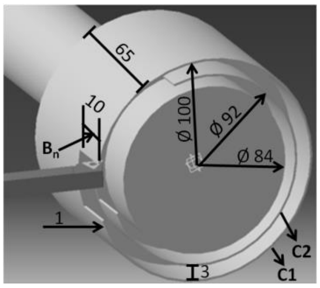


Figure 1. *Schematic design of workpiece.*

Orthogonal cutting test were performed by three cutting sections, in this case called Bn (distance of 10 mm equivalent to different ranges of *f*). Each section have two discs (C1,C2) with a width 1 mm (machined surfaces, called ap) to represent the range one of them according to cutting speed.

2.3 Cutting conditions

The tests were carried out in a parallel lathe Pinacho S-90/180, with tool insert from SECO supplier (TCMT16T308-F1 of coated TP2500) whose geometry cutting is close to orthogonal cutting. In order to maintain the same initial conditions were used new tools in each cutting test, see Figure 2.

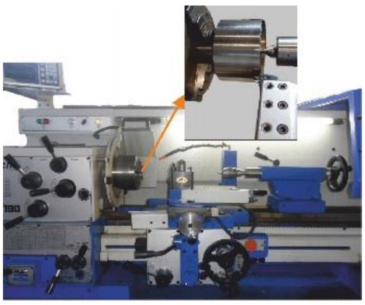


Figure 2. *Orthogonal cutting.*

2.4 Metallurgical and measurement setup

First step the chip morphology and tool characterized by geometrical measurements used monitoring system. In this case, was monitored by using a Olympus Stylus SH-60 Digital Camera (*ON LINE*) and the dimensional of chip was measured by an optical microscope NIKON model Optiphot 280 serie 460774, Kappa Image Base camera model CF11 DSP (*OFF LINE*) for this step was necessary to using metallurgical processes. Chips obtained after cutting process were mounted with epoxy and following the next steps: a) selection of chip, b) mounting in epoxy resin, c) mechanical grinding, d) polished to reveal their sections and the last step was: d) etching with Kroll´s reagent (50 ml H_2O + 2 ml HF + 5 ml HNO_3) for 20 seconds. See Figure 3.

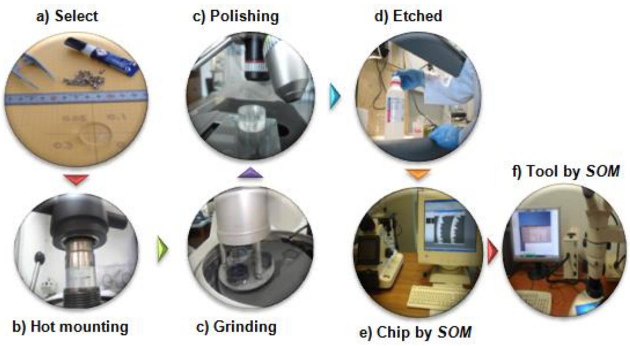


Figure 3. *Metallurgical setup.*

Finally, in this section was used image processing techniques as *SOM* (*Stereoscopic Optical Microscopy*) which help to characterized and determined the geometry chip and tool wear. And have been generally evaluated at some points (e. g. appearance and dimension) using the ISO 3685:1993 and UNE 16148 standards [7, 8]. The images were processing by ImageJ program (commercial software).

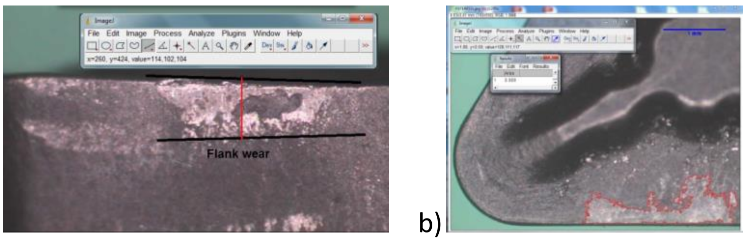
a)  b)

Figure 4. *Parameters measured: a) Flank and b) crater area using SOM technique.*

In another hand, this investigation focused into understanding by empirical analysis for tool wear monitoring in machining of *Ti6Al4V* alloy. In this case by analyzed the cutting force F_c and feed force F_f which were monitored by a piezoelectric a range 10 kHz, attached to a charge amplifier and for data acquisition was used Pulse Labshop software by Brüel & Kjær®. It is important to mention the cutting phenomenon in this case the cutting force as a function of the time to be filmed requires a short exposure time of the order of a few microseconds according to design of cutting process (see Figure 5).

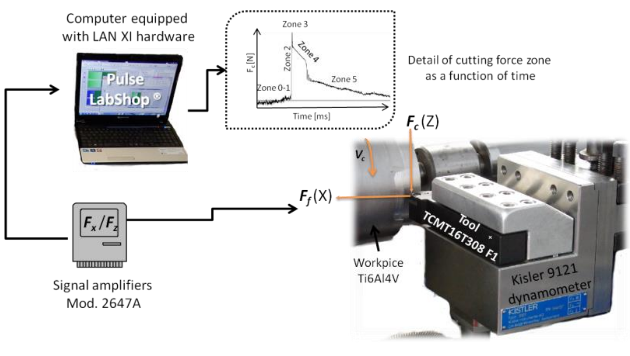


Figure 5. *Orthogonal cutting setup.*

In order to characterize the temporal evolution of the cutting forces exerted in the first stage of the machining (known as Quasi-Steady-State), it is necessary to analyze the amplitude of the extreme signal corresponding to the shearing force caused by the initial impact of the tool. For each tests were performed a graph is generated that represents the evolution of the cutting forces as a function of machining time (see Figure 6).

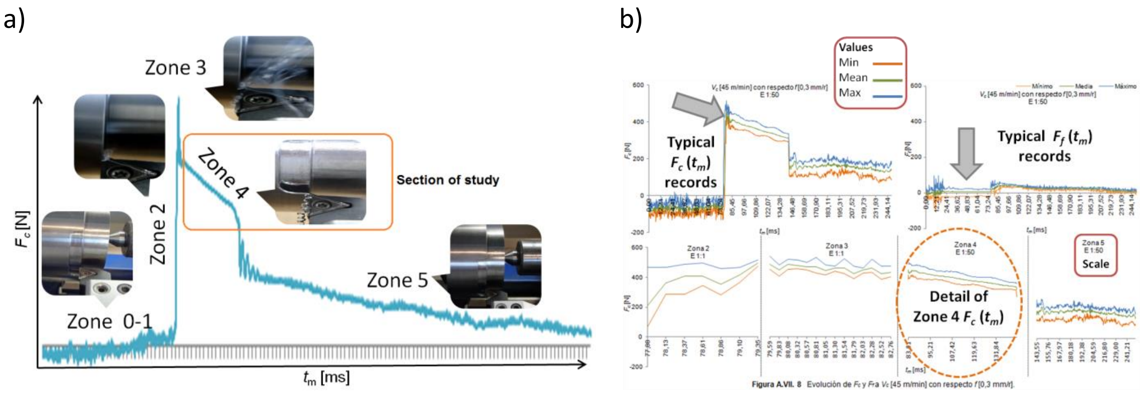


Figure 6. *a) Typical variation of F_c records and b) Typical spectrum records of F_c and F_f (only for F_c detail for the zones).*

Figure 6 a) shows the early stages of the process, 5 zones of study are identified: Zone 0-1, correspond to the time when the piece travels through the section known as relief t_d, coinciding with the first cutting instants (transient period); Zone 2, to represents the time interval t_2 in which the first significant changes of F_c are generated, until the maximum point is reached; Zone 3, display the maximum value of the forces during cutting process t_3; Zone 4, limits the quasi stable force interval to an instant before the end of the cut t_4; Finally, the Zone 5, represents the final stage of cutting process t_5. Therefore, the total machining time t_m is represented by the sum of the times consumed in these five zones in equation 1.

$$\mathrm{t_m} = \mathrm{t_d} + \mathrm{t_2} + \mathrm{t_3} + \mathrm{t_4} + \mathrm{t_5} \qquad (1)$$

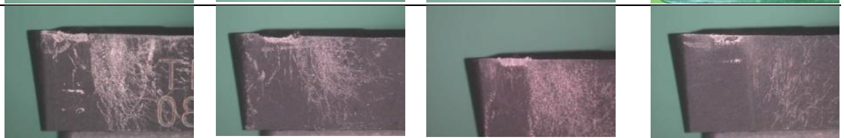
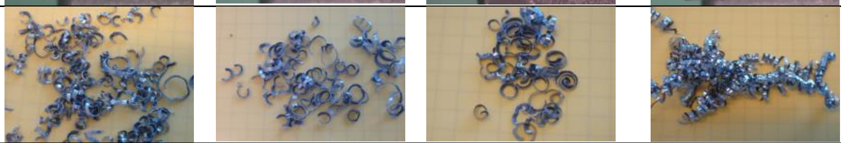
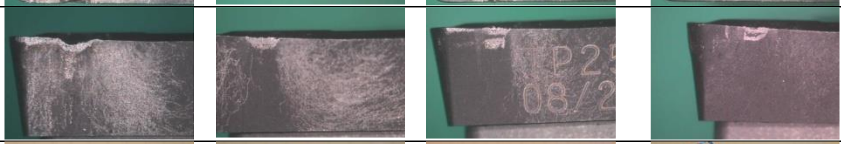
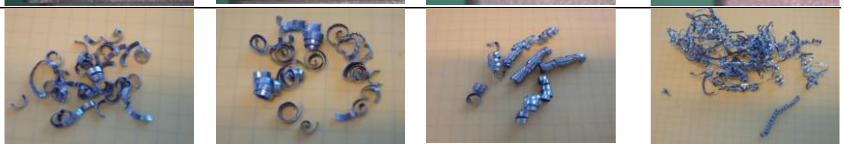
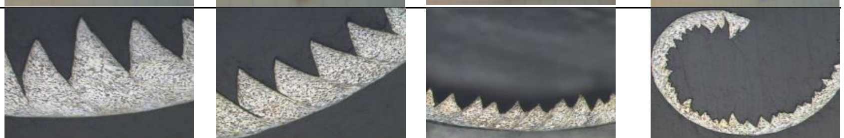
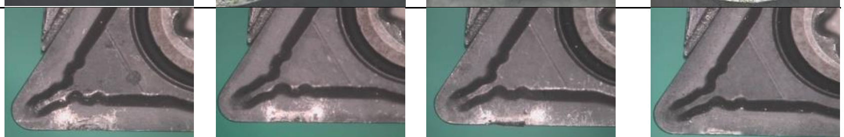
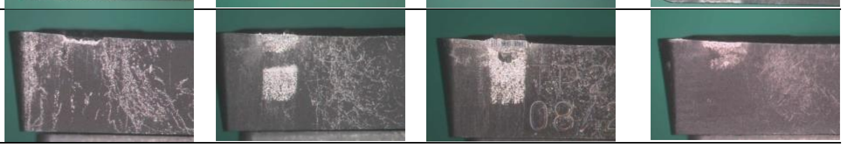
As shown in Figure 6 b) an example of cutting tests records. For each experimental test, typical plots, the time records of cut and cutting force are shown the average values of 10 cuts under the same cutting conditions (one range of f and V_c). This result includes minimum values, mean and maximum. At the same time in this plots can see only for F_c detail for the zones and each zone explain the scale of measurement. In this investigation has been considered to the Zone 4 (to eliminated the effect of the beginning and the exit of the cutting tool), the forces were determined by means value obtained in the tests performed in that zone. In another hand, into the Figure 6 b) shows the amplitude variation of feed force F_f caused by the contact with the chip, so its value represented around the 10% compared to maximum value of F_c in Zone 4.

3. Results

This study aims to better understand the evolution through a systematic study of titanium alloys (*Ti6Al4V*). Besides better understanding toward chip formation mechanism which can be good and convenient indicator of tool wear in machining process. Also, the knowledge on the cutting force evolution can improve manufacturing productivity where tool wear and workpiece dimensional accuracy need to be closely monitored.

The experimental results shown on the Table III on the first and second levels, the trends of chip geometry with similar serrated appearance in compared to other materials. In generally, the chip morphology characterization of *Ti6Al4V* alloy according to different values of f and V_c, the preliminary assessment was represented is generally continuous helical type, since the alloy has a high level of plasticity.

Table III. *Images of micrographs of the different chip types and wear mechanisms on tool rake and flank face during cutting process.*

V_c [m/min]		*f* [mm/r] 0, 3	0, 2	0, 1	0, 05
65	*Chip obtained in cutting process 1x*				
	Chip in SOM image 20x				
	Tool Rake face in SOM image 2x				
	Tool Flank face in SOM image 2x				
80	*Chip obtained in cutting process 1x*				
	Chip in SOM image 20x				
	Tool Rake face in SOM image 2x				
	Tool Flank face in SOM image 2x				
100	*Chip obtained in cutting process 1x*				
	Chip in SOM image 2x				
	Tool Rake face in SOM image 2x				
	Tool Flank face in SOM image 2x				

However, the table shown the experimental scenarios when *f* increase and also can be seen that a 0,3 mm/r the chip tends to be more fragment ability compared with 0,2 mm/r can be classified long tubular chip. In particularly, with 0,1 mm/r the chip is conical helical (segmented, more stable) on comparisons with other values, but the worst scenario, can be observed with low feed rate as is the case 0,05 mm/r, where chip is obtained in the form of tape with a tendency to form spiral chip snarled will be causing damage to the machined surface as the tool life. Furthermore, the last two levels shows images *SOM* 2x of tool wear during machining.

The physical mechanisms which produce of tool wear depend on the materials involved and the cuttings conditions specially the cutting speed. The purpose of this study is also to analyze and evaluated types of wear during cutting process by techniques *SOM*, shown on the Table III, whose result is evident, the tool wear progression in function of *f*. Another hand, this is due to increased efforts and pressures in the cutting zone, which facilitates the adhesion of the material to cause for thermo mechanical effects visualized on rake face of tool called *Built Up Layer* (*BUL*), displayed on the third level of table. Therefore, the wear appears when the geometry of chip is continuous form and causing stresses during contact with tool. In the case of *Built Up Edge* (*BUE*) their presence is unstable and caused by the formation of an adhesive layer of the workpiece caused by their ductility, shown fourth level of table.

The Figure 7 shown the experiments results are conducted in order to evaluated of the influence of V_c on *VB* is analyzed, It is observed that at high values of V_c a 65 m/min, the cutting edge increase failure and decreasing tool life and the average of tool flank is over to 0,2 mm. The cause of this has been adhered material in the cutting edge. However, at moderate speeds the tool shows a certain stability and ability to withstand the stresses generated in the machining.

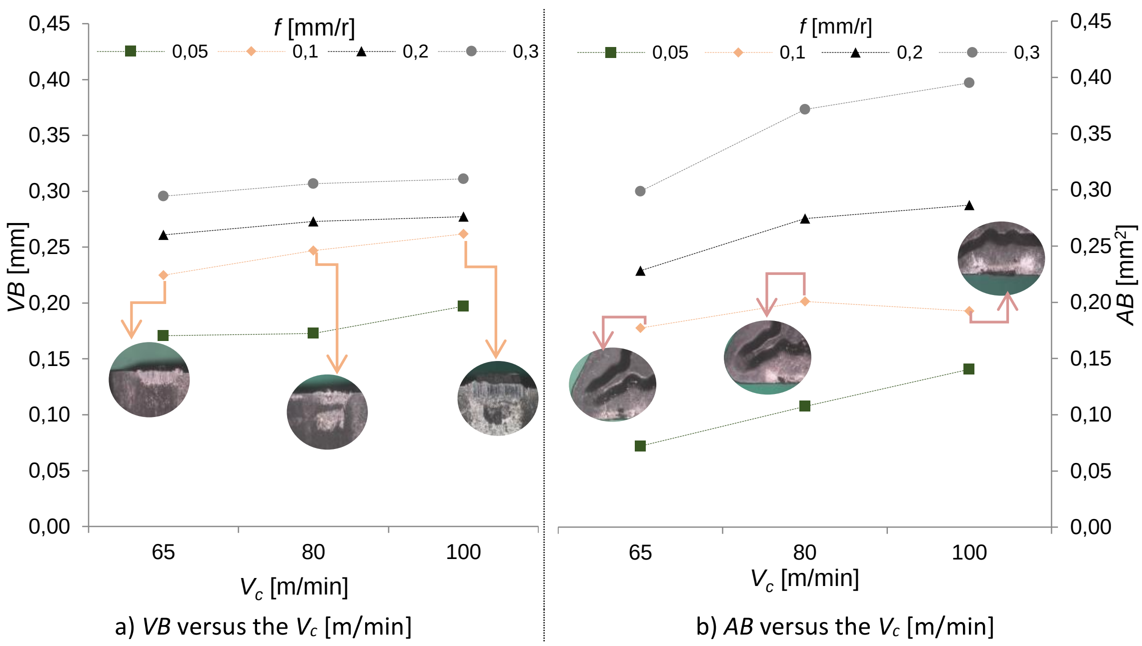


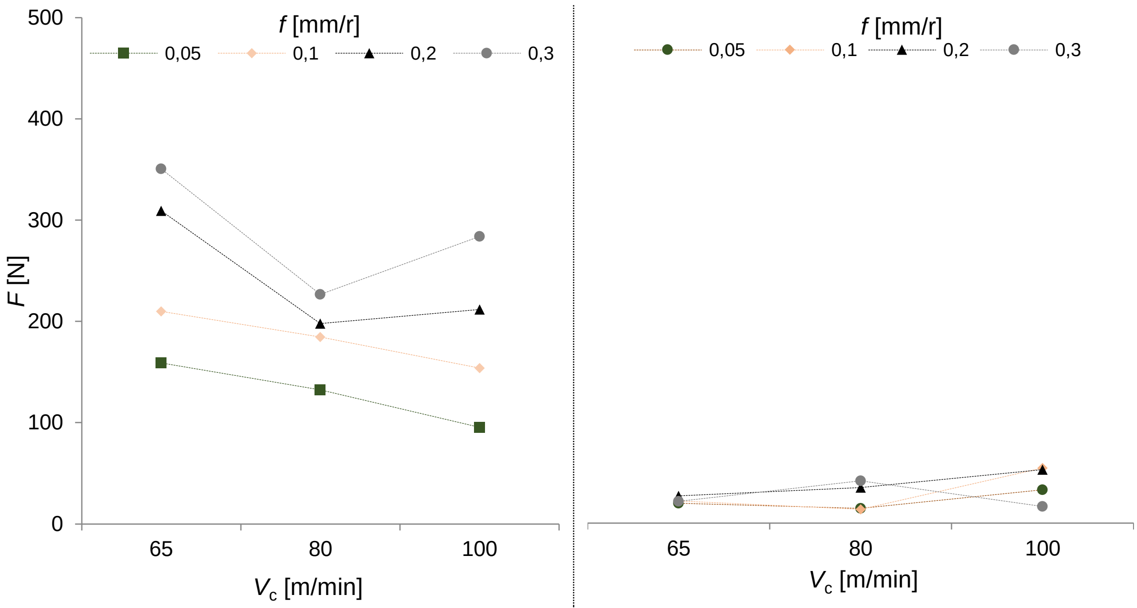
Figure 7. *a) Experiments results of flank wear VB versus the* V_c [m/min]*; b) Experiments results of rake wear AB versus the* V_c [m/min].

The Figure 7 b) has shown the qualitative dimension of crater area (*AB*) through measurements of under marks of adhesion on the surface of tool. This plot can help to understand the relationship to increase of V_c and wear mechanism on the rake face. In this case, if the crater formation will be increase the effective rake angle of the tool can be affecting by material adhesion and chemical reactions and could cause to reduced cutting forces. Another important factor to consider is not to be work with high ranges for *f* or should be avoided for this alloy because it makes to increase the crater area usually the results are associated with chemical solubility of the chip and high temperature of cutting in that zone.

Both plots included the example of progressive images are included for a value of *f* a 0,1 mm/r for each values of V_c. The results have been evaluated of International Standards Organization Criteria [7, 8].

According to the literature reviews [9-11] the modifications of the tool wear is associated with the appearance of shearing instability (changes of morphology of chip according to increase cutting parameters). This effect appears when overcoming level of plastic deformation of the material.

Finally, this part has been correlated that variations in the cutting force as function of cutting parameters. In this experimental investigation has been development of an *ON-LINE* tool wear monitoring system for *Ti6Al4V* turning operations. In this case by analyzed the cutting force F_c and feed force F_f which were monitored by force dynamometer. In the Figure 8 shown the quasi-stable entities of the sampled cutting force and feed force. In this case was extracted as the mean only the zone 4 respectively as function of cutting parameters of each experimental test.



a) F_c versus the V_c [m/min] b) F_f versus the V_c [m/min]

***Figure 8.** a) Typical variation experiments results of F_c and F_f versus different ranges of V_c [m/min].*

The Figure 8 a) showing the variation of average (mean values) F_c versus different ranges of V_c and f. This indicates that f is a variable that influences the behavior of F_c. In another hand, can been evaluated the tendency of F_c has been reduced considerably to respect of V_c, because the cutting temperature increases V_c, reducing the resistance of the material (thermal softening). Therefore, requires less effort in the tool.

In compared to the Figure 8 b) shows the values of F_f a declining trend over the 10% to 20% respect to the arithmetic average value of F_c. That mean the workpiece exerts greater pressure on the tool during impact on rake face, so the F_f is only be affected by friction of the chip in the flank of the tool.

4. Conclusions

This paper provides a detailed analysis by an indirect monitoring method of tool wear using the analysis of transient state of cutting force during dry machining of Ti alloys. The result helps to understand the process of chip morphology into relation with cutting force and wear mechanisms of the tool. This behaviour can be determinate the best cutting condition combination.

A methodology has been developed to characterization of morphologically and geometrically the chip in the dry turning process of *Ti6Al4V* alloy into relation with cutting parameters. In this case, to evaluated of geometry of the chip according to the tool wear and cutting forces during the machining process.

The data obtained, it has been possible to consider, as complementary lines, the macrogeometric evaluation of the chip in relation to cutting forces. The chip morphology of the fragmented sawtooth type has been identified as a function of different ranges of f as V_c. However, as f is increased, the thickness of the chip increases considerably, being related to the growth of shear forces required to remove said chip. According to the experimental results, the proposed methodology can provide and identify of chip geometry the alloy *Ti6Al4V* with respect to cutting parameters and also was validated the morphology of chip in relation to the ISO 3685:1993 and UNE 16148 standards. And the same time, the results also was validated with some literature reviews as [12-15]

Through of experimental was possible to identify and understand that increased values of *f* the tool wear progression becomes larger, more unstable and can to adversely residual affect the machined surface and chip geometry. Results for tool wear in this case flank wear has revealed promising candidate to control cost and performance of cutting process for *Ti6Al4V* alloy.

This experimental test is proposed another option to obtain the natural frequency of cutting force and to permits to select the studies to relation with records obtained during of cut. The results have been compared and validated by studies obtained from bibliographical references.

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