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PROGRESS ANALYSIS OF WEAR IN CARBIDES INSERTS DURING MILLING ABNT 4340 STEEL BARS WITH DIFFERENT LENGHTS

Lucas Emmanuel Abreu Rezende
Sandro Cardoso Santos
Centro Federal de Educação Tecnológica de Minas Gerais – CEFET-MG
Av. Amazonas, 7675, Nova Gameleira, Belo Horizonte, Minas Gerais, Brasil.
sandro@des.cefetmg.br

Diêgo Fernandes da Cruz
Centro Federal de Educação Tecnológica de Minas Gerais – CEFET-MG
Av. Amazonas, 7675, Nova Gameleira, Belo Horizonte, Minas Gerais, Brasil.
diegofernandesdacruz@yahoo.com.br

Abstract. *This paper presents a preliminary study about the interaction between workpieces and tools in processes of interrupted cutting. The objective is to understand and evaluate the effects caused by the number of outputs and inputs tool on the workpiece through wear dimension in carbide inserts. Therefore were applied carbide inserts and ABNT 4340 steel bars with 200 and 400mm in length. All cutting parameters were kept constants for both situations: cutting speed, feed rate, cutting depth, number of outputs and inputs and penetration work. After machining a sequence of steps, all edges in cutting were applied singly to a superficial analysis in a measuring microscope and had their flank wear growth measured. At the end of the tests, it was possible to notice that all edges in cutting showed prematures wearing out of the flanks and craters wear. It was also noticed that the tool wear had a remarkable sharp rise when short workpieces were machined. So, it was noticed that the number of outputs and inputs tool wasn't the determinant factor to cause an increase on wear evolution.*

Keywords: *milling, inserts, wear.*

1. INTRODUCTION

Machining is the most widely used process in the industries. For this reason the researches for the reduction on the costs and manufacturing time are critical. All involved processes or practices applied in engineering there are standards that ensure their use. Through these, domestic and foreign industries can adopt the same classification to define the machining processes, thus facilitating the process of communication and technical exchange, ensuring product reliability and the correct understanding of manuals and documents related to the project (TUDELA, 1998). The machining process is made by applying one or more steps. These steps are defined, in short, by the time the multi-cutting tool begins its cut (input) and closes the material removal (output). In this sense, every step has an input and an output.

Along with turning and grinding operations, the milling process represents a considerable proportion of the utilization of the machining process, since it allows to machine unconventional shapes. This last process is different from all other machining processes since there is a cutting interruption after the cutting tooth to move out of the working surface; there are two milling combined movements and the chips obtained have relatively small sizes and are discontinuous, as well as there is a variation in the thickness thereof (ASM HANDBOOK, 1987) along its length. For this reason, it isn't only necessary to understand the process, but also the parameters that influences the final results, for example, the lifetime of the inserts and their wear rates.

The technological advances in the machining processes have required the reduction in the production times. The attainment of more demanding materials on ways to work and the desire for increased income generated demanded the creation of cutting tools with complex geometries and materials (SANTOS and SALES, 2007). So, the application of these new materials allowed drastic increase in cutting speed, thus meeting the needs of entrepreneurs. Also it demonstrated vulnerabilities in parts and equipment. Raise the cutting speed mean to increase the cutting force, friction and heat buildup. Thus, due to uncontrolled dimensional thermal expansion means increasing the wear of the equipment, generating rust formation and, in some cases, change the material's microstructure to be worked. In this sense it is important to know the types of faults present in the tooling: damage, wear and plastic deformation.

Unlike the turning process which has uniform wear has over the rake angle (γ) or incidence (α); in milling process, where the cut is interrupted, the cutting forces are cyclical in the input, during and in the output cutting throughout the pass (SANTOS and SALES, 2007). Wear flank means increasing the friction between this region and the workpiece, generating higher temperatures and dimensional part disarray. Therefore some papers in the ASM HANBOOK (1987) propose a representation of a characteristic wear evolution curve of a tool taking into account certain tool life criteria (Fig. 1). In stage I, the inflection is the inserts' adaptation period to the machined materials and cutting parameters. In stage II, the curve represents the wear of the tool as a function of time using this same insert. The inserts present wear increase behavior almost linear. At stage III, the inflection grows abruptly, which means that the insert has achieved high temperatures and stresses, resulting in breakage of the cutting tool.

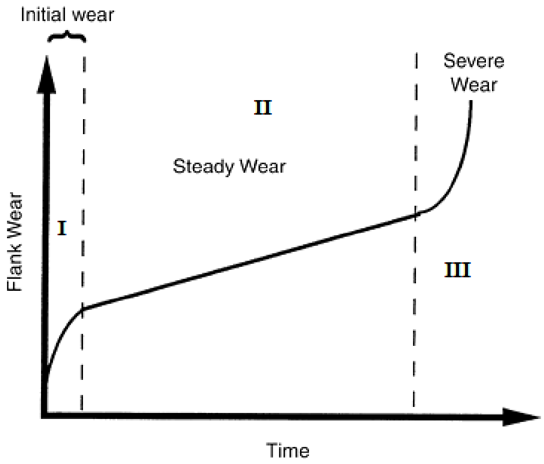


Figure 1. Standard curve of wear phase for inserts.

Runge (1989) and the collection papers in the ASM HANBOOK (1992) investigated the inserts' temperature on interrupted cutting. They noted that the temperatures were cyclical and suddenly causes, for many cases, micro thermal cracking and later insert's fracture (VIEIRA, 2001). The lack of control over the wear mechanism and formation of damage to the insert can cause premature loss of this insert as well as defects in the machinery and non-compliance on machined surfaces.

2. METHODOLOGY

2.1 Experimental setup

The workpiece material used in the milling test was the ABNT 4340 steel bar. It was found in annealed condition and hardness equivalent to 42HRC. Two squares section blocks for testing were used. The first with the dimensions of 200x103x103mm and the second with 400x103x103mm. The chemical composition of the steel is showed in Table 1 (SCHMOLZ BICKENBACK, 2014):

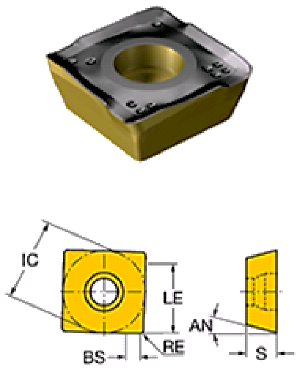
Table 1. Chemical composition of the ABNT 4340 steel bar.

C %	Fe%	Si %	Mn %	P %	S %	Cr %	Mo %	Ni %
0,37 - 0,43	Rest	0,15 - 0,35	0,60 - 0,80	Less than 0,025	Less than 0,025	0,70 - 0,90	0,20 - 0,30	1,65 - 2,00

The mill used in the machining test was a SANDVIK 490-040Q16-08M 260480 and the coated carbides inserts were a SANDVIK 490R-08T308M-PM 4240. The tool diameter was 40 mm (SANDVIK COROMANT, 2014).

The insert had a carbide substrate, coated with triple layer: TiCN, a middle layer of Al_2O_3 featuring thermal stability and wear resistance (LI, ZENG and CHEN, 2006), and an outer coated layer of TiN featuring low friction and adherence resistance.

The insert information is shown in Fig. 2 (SANDVIK COROMANT, 2014). The machine tool used in the cutting test was a DIPLOMAT FVF 3000 (DEB'MAQ, 2014), three-axis vertical milling machine tool with manual controller. The machine table could be moved in Cartesian coordinates in x, y, and z direction. The workpiece was mounted on the manual bench vise.



Model	490R-08T308M-PM 4240	
RE	Corner radius	0.8 mm
BS	Wiper edge length	1.2 mm
S	Insert thickness	3.3 mm
IC	Inscribed circle diameter	8.5 mm
AN	Clearance angle major	15°
LE	Cutting edge effective length	5.6 mm
	Coating	CVD
	Cutting edge count	4
	Hand	R (Right)
	Operation type	Medium
	Depht of cut maximum	5.5 mm

Figure 2. Product description about the carbide insert applied.

For the measurement of the inserts' wear was used a microscope BK 70x50, by ZEISS company whose resolution is 0,001 mm. On the ocular lens it was adapted a cell phone camera SAMSUNG S4 MINI, with a 8,0 Megapixels resolution. The autofocus allowed the camera to align the focus of the microscope, facilitating the collection of images.

2.2 Experimental procedure

Four inserts, identified separately from 1 to 4, were positioned on the cutter through the fixing screws considering the same identified edges position upon the insert. These marks allow to track which of the edges were used. The edge position 1 was used to make the setups of the machining equipment.

The automatic table feed rate was defined by a potentiometer between 0 and 9 levels. Once the feed rate is independent of the shaft rotation and feed rate values were not presented in the technical equipment manual (DEQ 'MAQ, 2014) it was necessary to quantify them. First, a distance between limit switch was set to the table when triggered automatic movement (about 640mm). Once it was done it was necessary just to time the trigger time these limit switches. Thus, the feed rate (V_f) can be calculated by the relation (Eq. 1) between the push time switches (t) and the distance between them (d):

$$d/t = V_f \tag{1}$$

The rotational frequency (n) has been chosen in function of Eq. 2, whereas the feed per tooth (f_z) and cutting edges (z) were 0,1 mm / min and 4, respectively.

$$V_f/(z * n) = f_z \tag{2}$$

All values are parameterized as a function of revolutions per minute (Tab. 2), according to Eq. 1 and 2. In this case, this rotational frequency was maintained at 1400 rpm as measured by a laser tachometer.

Table 2. Parameterization of feed per tooth and revolution according to the insert features, the cutter, the forward speed and the revolution per minute.

	Time between the push time switches [s]					
Potentiometer Position	Time 1	Time 2	Time 3	Average Time [s]	Feed rate [mm/min]	Feed for tooth [mm/tooth]
0	0	0	0	0,0	-	-
1	0	0	0	0,0	-	-
2	214	152	171	179	214,53	0,04
3	106	104	114	108	355,56	0,06
4	93	85	93	90,33	425,09	0,08
5	88	82	84	84,67	453,54	0,08
6	74	79	73	75,33	509,73	0.09
7	77	72	75	74,67	514,29	0,09
8	70	76	71	72,33	530,88	0,09
9	70	69	73	70,67	543,40	0,10

Diameter milling cutter [mm]	Revolution per minutes [rpm]
40	1400

Cutting edges	4

Cutting speed [m/min]
175,93

Thus, the defined machining parameters were the 9th position, automatic table feed rate 543 mm/min, cutting speed 176 m/min, depth of cut (a_p) equivalent to 1 mm and penetration work (a_e) for each step, with 36mm.

After the setup of the equipment the cutting edge has been positioned considering the 2nd mark upon the insert, enabling the beginning of test. The milling took place in two stages: first the shorter block (block A) was machined, and subsequently the larger (block B). As reference shown in Fig. 3, this operation has occurred in the length direction (x axis) for both them.

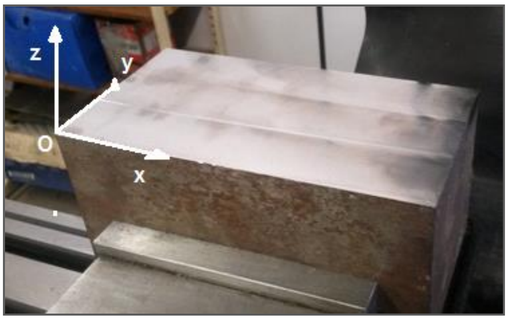


Figure 3. Experimental setup.

Every three steps, i.e., 3 inputs and 3 outputs, each insert was removed and observed separately under a microscope. Proposed holding such observations for 42 steps. Accordingly, the block B has twice the total length (L) of the milling block A. Thus it evaluated the state of the inserts on the 2nd position to the flanks and the top surface, which was represented by the letter "S" and was also preceded by the numbering of the insert.

The flanks designed by the edges marked with 1st and 2nd position were represented by "F_{12}". Since the flanks formed by the 2nd and 3rd edges were represented by "F_{23}". In both cases such suffixes were again preceded by the numbering of the tablet. Briefly, in Tab. 3, we have:

Table 3. Representation of view of each of the inserts intended for the machining of the blocks.

	BLOCK A				BLOCK B			
	Insert 1	Insert 2	Insert 3	Insert 4	Insert 1	Insert 2	Insert 3	Insert 4
Upper view	1S	2S	3S	4S	1S'	2S'	3S'	4S'
Flank between first em second mark	$1F_{12}$	$2F_{12}$	$3F_{12}$	$4F_{12}$	$1F'_{12}$	$2F'_{12}$	$3F'_{12}$	$4F'_{12}$
Flank between second and third mark	$1F_{23}$	$2F_{23}$	$3F_{23}$	$4F_{23}$	--	--	--	--
Flank between second and fourth mark	--	--	--	--	$1F'_{14}$	$2F'_{14}$	$3F'_{14}$	$4F'_{14}$

The analysis under the microscope consisted of inspection and evaluation of wear regions on the upper plane and the insert's flanks. These regions worn was measured and after photographed by a camera. Each insert was evaluated repeatedly after the third, ninth, fifteenth and twenty-first steps. Subsequently analyzed, these inserts were relocated to the mill respecting their original position. In this way it was possible to start a new cycle just regulating the cutting depth. After the machining the shorter block, the inserts were replaced with new ones and the procedures were repeated for the Block B.

All data collected were evaluated and graphically arranged in order to compare the rate of wear of the inserts. Thus it was possible to obtain the conclusions presented at the end of this paper.

3. RESULTS AND DISCUTION

Once the tests are the same for all inserts, it was decided to show only the images concerning the second insert. Thus, in Fig. 4 shows the status of these inserts before starting the machining of the blocks A and B. As noted, none of the inserts in their initial state present flank wear, crater or notch, apparent formation of micro cracks or built-up edge. However flanks present some partial burning of the CVD coating.

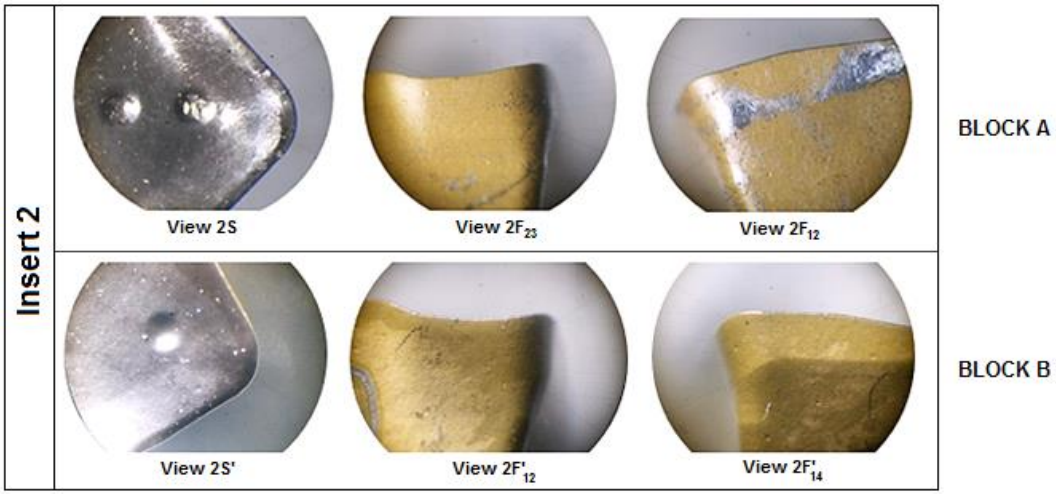


Figure 4. State of the inserts after the setup of the equipment.

3.1 Analyzing the wear of the second insert for the block A

As showed in Fig. 5, view $2F_{23}$, there was adhered the material that was removed from the workpiece. For Fig. 6, it was observed in view 2S that the crater wear began to be formed.

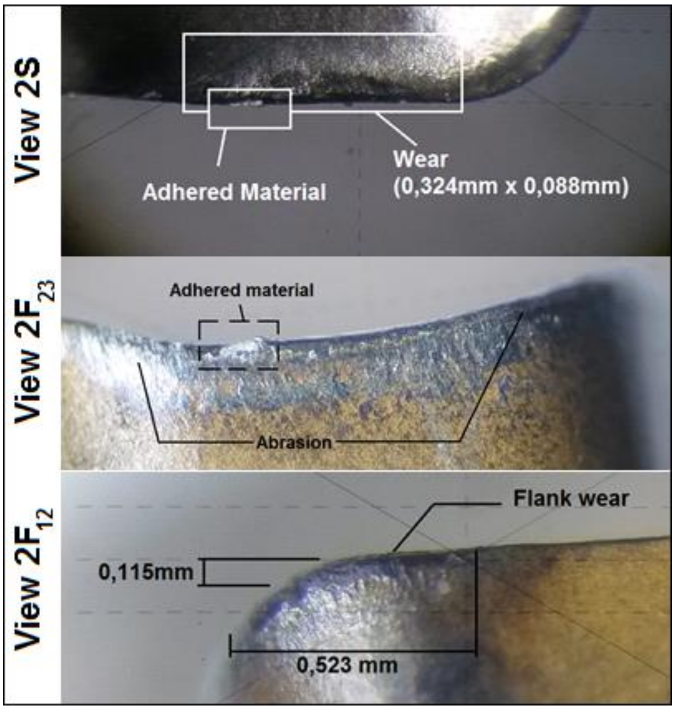


Figure 5. Conditions of the insert after the third step

In practice this wear would be nothing more than a flank wear of island growth which would be located at the tool tip. It was also noted that after the 9^{th} step the material adhered to the edge of this insert it detached formed giving rise to a flank wear region, possibly by adhesion mechanism (Fig. 6, $2F_{23}$).

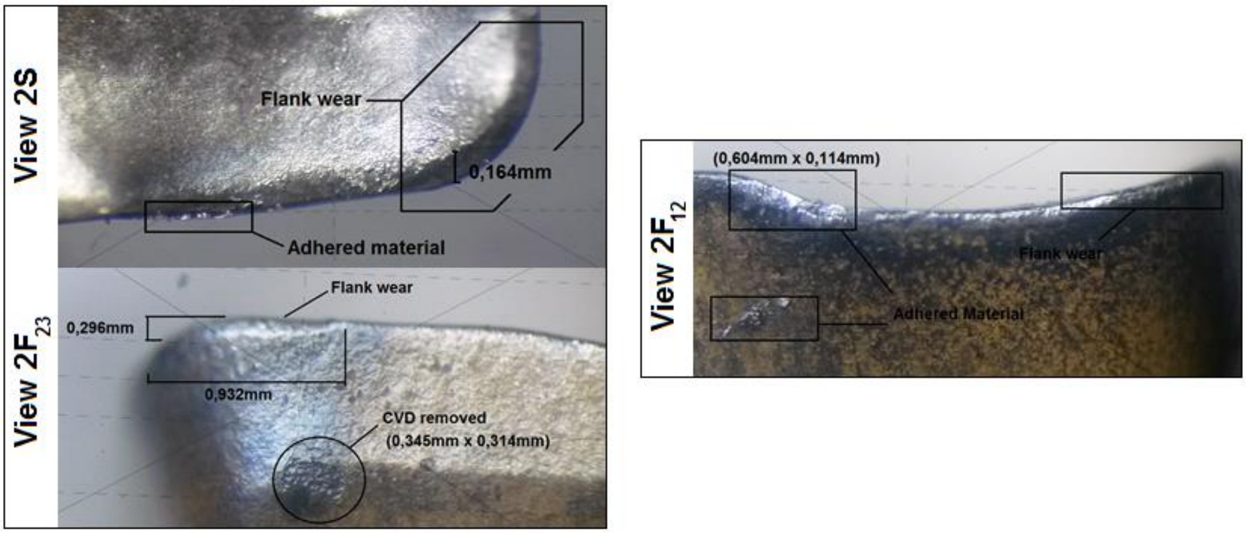


Figure 6. Conditions of the insert after the twenty first step.

3.2 Analyzing the wear of the second pad for the block B

In Fig. 7 is showed the initial stage of wear, as suggested by Ferraresi (1969), which can be seen in $2F'_{12}$. As expected, the insert did not present expressive wear.

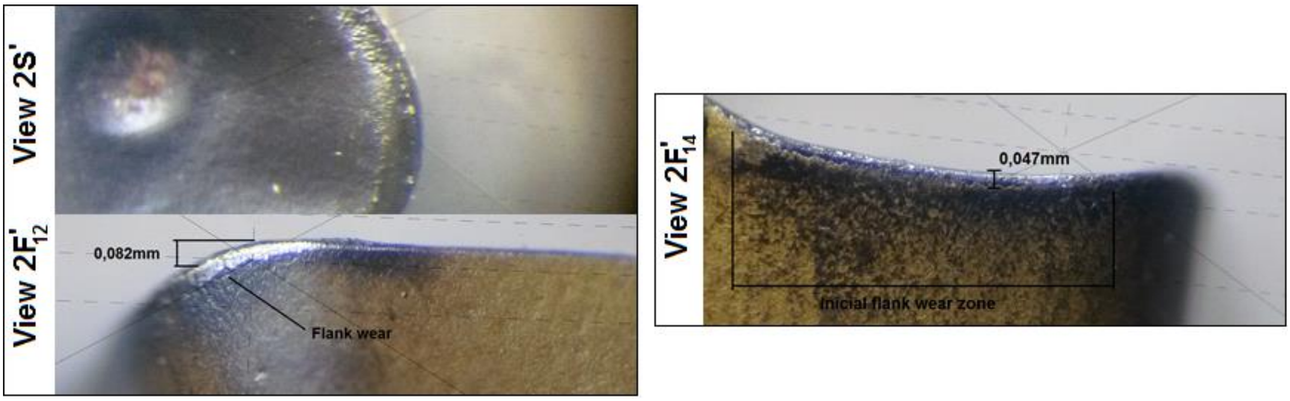


Figure 7. Conditions of the insert after the third step.

Throughout the ninth, fifteenth and twenty-first steps (Fig. 8) the wear areas increase, especially in the tool tip.

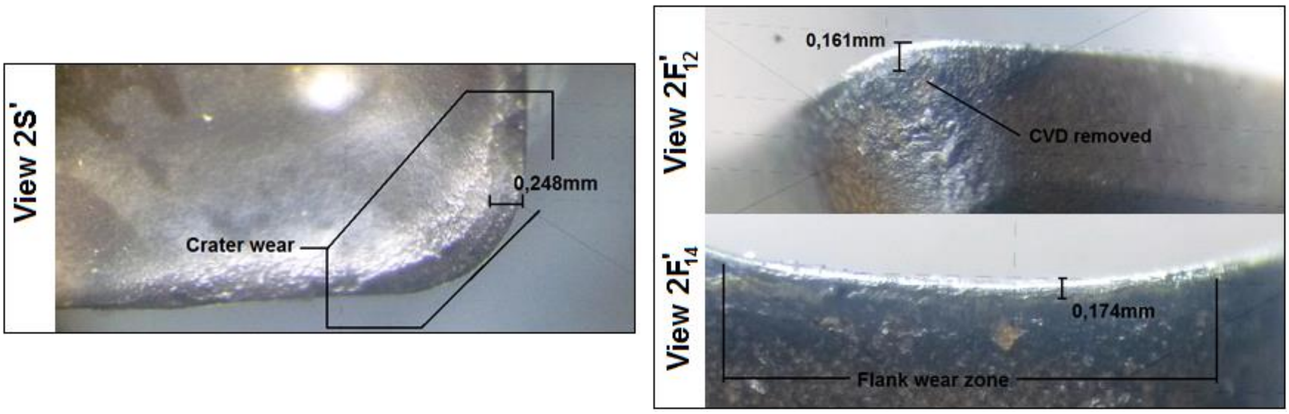


Figure 8. Conditions of the insert after the twenty first step.

3.3 Comparing the wear of the inserts

By comparison, it is necessary to evaluate the wear of the inserts. For Tab. 4 presents the measured flank wear generated by each insert relating to the shorter length block.

Table 4. Inserts' wear observed in F'_{12} view of the shorter machined block and F'_{14} view of the larger block.

	Flank Wear Insert for Block A [mm]					Flank Wear Insert for Block B [mm]				
Step	**Insert 1**	**Insert 2**	**Insert 3**	**Insert 4**	**Standard Deviation (σ)**	**Insert 1**	**Insert 2**	**Insert 3**	**Insert 4**	**Standard Deviation (σ)**
0	0	0	0	0	0	0	0	0	0	0
3º	0,113	0,115	0,104	0,076	0,0180	0,053	0,082	0,057	0,062	0,0129
9º	0,152	0,126	0,172	0,158	0,0193	0,125	0,116	0,136	0,103	0,0140
15º	0,195	0,217	0,216	0,204	0,0105	0,135	0,132	0,163	0,135	0,0146
21º	0,274	0,296	0,283	0,268	0,0122	0,154	0,161	0,204	0,198	0,0254

The results presented in Table 4 are shown in the graphics of Fig. 10.

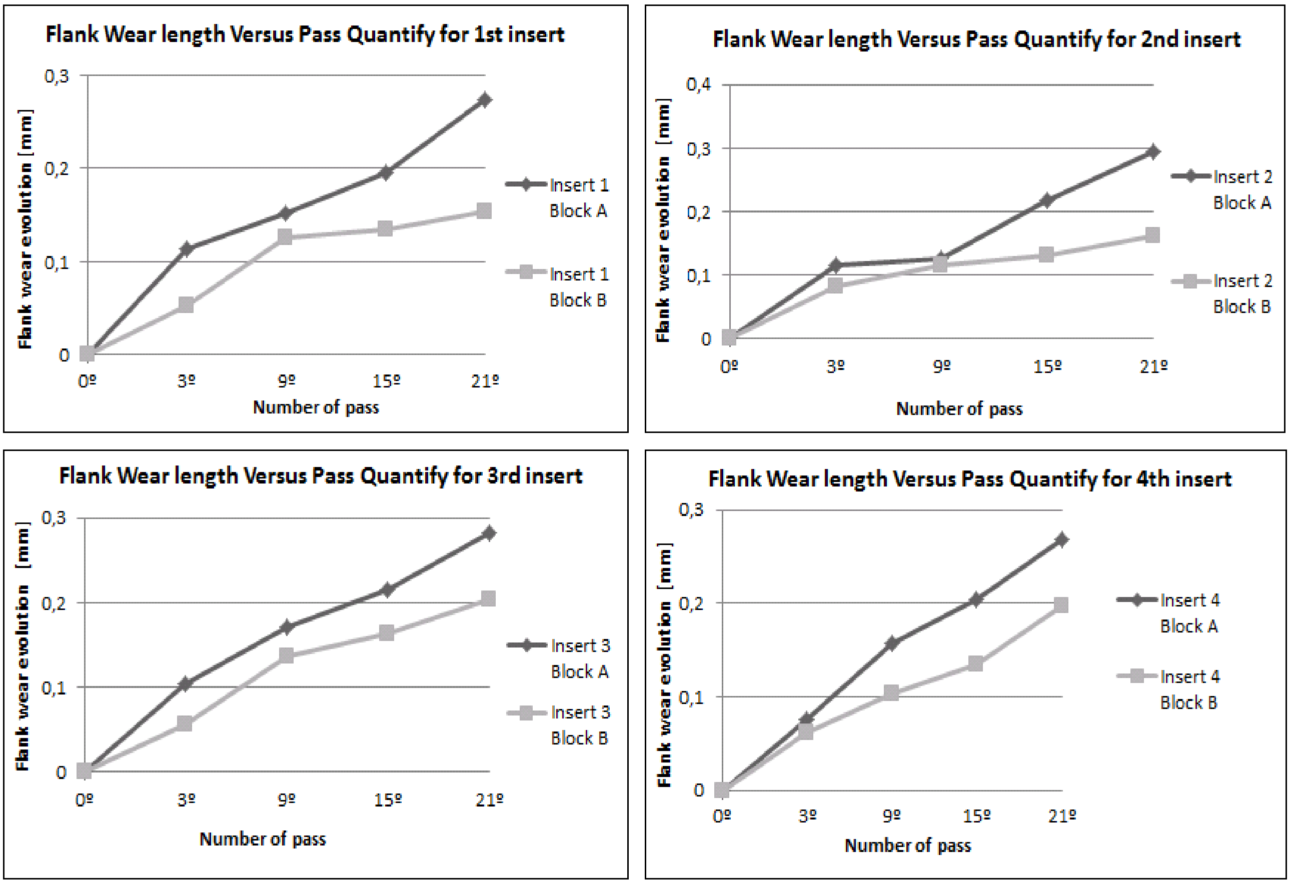


Figure 3. Comparison of flank wear measured in sight F_{12} and F'_{14} after machining of ABNT 4340 steel bars.

By indicators previously presented, it was possible to evaluate the size of the wear zones for each of the inserts according to the number of steps. It was further noticed that the ABNT 4340 steel bar with 200mm had higher growth rate of wear than the other block in all cases. After the third step the wear formed was small, meaning that the tooling was adjusting the tribological system. Significant differences in wear, mainly on the flank, were identified only after the fifteenth step. At that time, it could already be observed by the peeling and removal of the coating layer as well as regions with material attached to the substrate regions of the inserts and potentially formed by plastic deformation mechanism.

Initially, the objective was to evaluate the wear comparing the amount of volume of material removed. Thus it would be necessary to make double steps in the shorter block so that the same chips' volume produced was reached during the machining of the larger block while it would have half the cutting time (t_c), Equation 3, is applied in block B. So, for the shorter block its cutting time is 0,36s and for the other 0,72s.

$$L / V_f = L / (f_z * z * n) = t_c \quad (3)$$

However after the 21 proposed steps, the inserts used during the machining of the shorter block had already a remarkable wear although it had just half the length machined applied in 400mm block.

4. CONCLUSIONS

Given the complexity of the wear mechanisms and temperature gradient in the chip-tool interface many considerations were made aiming to develop a simple work and easy to be repeated. After all the tests, it was observed in all images the formation of wear springs states flanks and, clearly, crater wear after the ninth step (both caused by the abrasion process). The latter type of wear does not directly influence the roughness or tolerance of the workpiece, since it was formed over the tool rake surface, but significantly changes on the length and format of the chip, since this it flows over this surface.

Through the tests it was not possible to reach the end of the tool life, as proposed in the ISO 3685, nor was it possible to evaluate the deep of the craters wear. This might have occurred because the inserts were subjected to optimal machining conditions. It is noteworthy that despite the variation between the amount of impacts for both tests, this difference was not significant. Thus, the determining parameter would be the cutting time, since it depends directly on the machined length.

The results indicate that the number of inputs and outputs of the tools in the workpiece was not the only factor that influenced the tool wear behavior, because the machining of the short workpiece caused greater tool wear than observed when machining larger workpiece for the same number of inputs and outputs.

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6. RESPONSIBILITY NOTICE