

PERFORMANCE OF AN INTERNALLY COOLED TOOL HOLDER WHEN TURNING ABNT 1045 STEEL

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Abstract. *This work analyzed the performance of an adopted Internally Cooled Tool Holder – ICT. in a closed loop during the turning operation of an ABNT 1045 Steel. The input variable was the ambient ICT and dry machining, while feed rate ($f = 0.40$ mm/rev), rotation ($n = 1\ 020$ rpm) and depth of cut ($doc = 0.4$ mm) were kept constant. The output variables were roughness (R_a), quantitative and wear mechanisms, qualitative. The main conclusions are that dry and I.C.T. conditions for roughness had the same statistical results, indicating that I.C.T. does not act over the workpiece. The tool's wear analysis observed micro chippings, adhesion, and plastic deformation (flank wear) for both dry and I.C.T. However, the wear was much more pronounced in dry conditions, indicating that I.C.T. helps keep the tool cool, preserving it. Finally, I.C.T. showed to be a promising sustainable, eco-friendly technique. However, complementary studies are necessary.*

Keywords: *Internally Cooled Tool Holder - I.C.T., sustainable, 1045 steel, turning, eco-friendly machining,*

1. INTRODUCTION

Machining is a complex process of a nonlinear nature, which involves high frictional heat generation between two surfaces (tool/part) in a reduced contact area with high localized temperatures. It is estimated that almost all mechanical work is converted into heat during the cutting (Abukhshim et al., 2006; Luchesi & Coelho, 2012). This heat is distributed among the cut's elements: piece, chip, tool, and ambient. It is generated in the three shear zones, primary shear, secondary, and the interface between the tool and the part. It increases the temperature in the process and can cause: loss of dimensional tolerance; poor surface integrity (roughness, stresses, micro-cracks); lower cutting parameters with loss of productivity; shorter tool life. Other factors include chip removal and adhesion of certain materials, Build-up Edge (BuE) formation, vibration and shake, excessive cutting forces, and hardening work (Childs et al., 2000; Klocke, 2011; Machado et al., 2011; Trent & Wright, 2000).

Santos & Sales (2007) still add that the temperature rise's consequences reduce its life and limit the cutting parameters, mainly cutting speed and feed rate. Therefore, the cutting temperature is one of the most significant quantities in the machining processes, which justifies the accomplishment of studies that seek to measure, evaluate, and control its influence on the cutting tool's performance. Trent and Wright (2000) cite that the cost of machining is strongly dependent on the material rate removal, so the limits in cutting speed and feed also end up impacting this cost.

Cutting Fluid in Abundance – C.F.A. is the standard technique used in machining operations to reduce temperature and avoid its harmful effects. It acts primarily as lubricants and coolants and protects the parts against oxidation and removing chips from the cutting zone (Byers, 2016). However, C.F.A.s can contain more than ten different additives, just as bactericides and fungicides, that is environmentally harmful and can generate contamination of soil, rivers, in addition to causing health problems to the operator who is in contact with it (Bartz, 2001; Ozcelik et al., 2011; Shashidhara & Jayaram, 2010).

These aspects have led to the research and development of new techniques that can reduce, or even eliminate, the use of C.F.A. in machining (Lisboa et al., 2013). With these studies, new alternatives have emerged based on economic and productive aspects; in addition to the environmental concern mentioned above, one of these alternatives is the I.C.T. (Internally Cooled Tool holder) (Jeffries & Zerkle, 1970).

The idea of indirectly cooling the tool during the machining process is not new. In 1970, Jeffries e Zerkle (1970) proposed a mathematical thermal analysis of an I.C.T. for orthogonal cutting considering new and flank-worn tools. Results demonstrated that it could result in significant temperature reduction along the rake and flank face. However, no details were given about the cooling method, and no experiments were performed (Jeffries & Zerkle, 1970). One year after, the authors obtained a U.S. patent, number US3571877A, containing an internal chamber for heat exchange (Zerkle, 1971).

Since then, the indirect cooling method has been the subject of many studies because it is a more economical alternative and an ecological solution to replace cutting fluids. It could also be used in the tool holder. Vicentin (2010) and Neto et al. (2015) present in their work a tool holder with internal cooling with fluid phase change. Vicentin (2010) carried out his experiments with stainless steel VV50, comparing the dry, C.F.A., and indirect cooling ambient, observing their effects on the tool's life. Its results indicated the effectiveness of the proposed cooled tool holder, obtaining tool wear values equal to or even better than C.F.A. Neto (2014), carried out experiments using ABNT 1045 steel and SEA XEV-F stainless steel. He also set up a circulation system for the coolant fluid together with a condenser since the refrigerant used (R-141b, from Dupont) was volatile at room temperature, working with negative temperatures close to -4°C (Fig. 1).

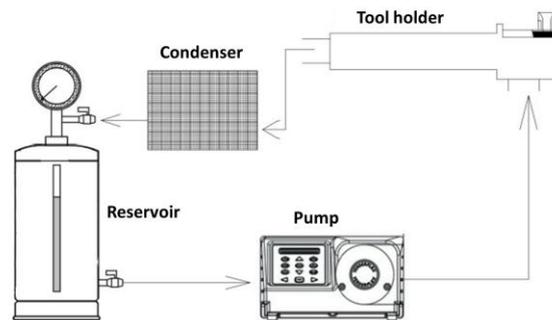


Figure 1. Diagram of the changing phase coolant circulation and condensation system proposed by Neto et al. (2015).

Neto (2014) concluded that for AISI 1045 steel machining, internal cooling proved to decrease the cutting temperature, reducing the wear mechanisms such as oxidation and adhesion, which are thermally activated. However, for SEA XEV-F stainless steel, the results were not as effective as the C.F.A. condition due to the lubricating lack of action. Therefore, the abrasive wear mechanism was pronounced because of the material, which has chromium carbides, and due to the thermal conductivity of this steel. On the other hand, the volume of material removed with the internal cooling system was higher than the dry cut, characterizing some productivity gains when the emulsion cannot be used. They also observed that when the cutting parameters are softer, the internal cooling is more effective in prolonging the service tool life.

The iron-carbon alloys containing between 0.008 and 2.11 % C by weight are classified as steels. It has a wide range of applications due to its low cost of obtaining, associated with great versatility of properties that can be obtained from small changes in chemical composition, heat treatments, and/or processing, and mainly the high ductility combined with outstanding tenacity and high hardness (Davis et al., 1990).

According to international AISI (American Iron and Steel Institute) and Society of Automotive Engineers (S.A.E.), and Brazilian national standards ABNT (*Associação Brasileira de Normas Técnicas*), steels classification system is based on their chemical composition (González Santos, 2008). Following the standard NBR NM 87/2000, which establishes the chemical compositions of steels for mechanical construction, ABNT 1045 steel, or AISI 1045, must present chemical composition described in Table 1 (N.B.R., 2000 apud Azevedo, 2002).

Table 1. Chemical composition of ABNT 1045 steel (% by mass) (N.B.R., 2000)

C	Mn	Pmax	Smax	Si
0.43 ~ 0.50	0.60 ~ 0.90	0.04	0.05	0.10 ~ 0.60

The carbon steel alloy of the ABNT 1045 family consists of perlite and pro eutectoid ferrite microstructure (Fig. 2). This formation allows the steel to have medium voltage supported when normalized or hot rolled, and its tensile strength limit between 570 to 700 MPa, and its Brinell hardness ranges from 170 to 210 HB (Batista, 2019).

The main objective of this work is to analyze the effect of indirect cooling a tool holder with an internal fluid circulation system during the turning of ABNT 1045 steel. For this, a mixture of water and mono ethylene glycol at room temperature ($\sim 25^{\circ}\text{C}$) was pumped. The output variable was the tool life and surface finish quality of the machined part.

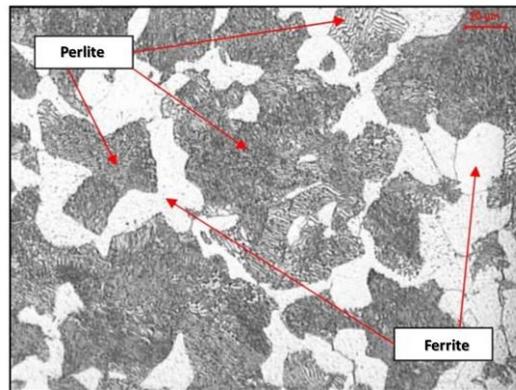


Figure 2. ABNT 1045 steel microstructure (González Santos, 2008)

2. MATERIALS AND METHODS

2.1 Cooling System Design

For the machining process, a unique tool holder was adopted. It was used the same one designed by Figueiredo (2015), Fig. 3. This tool holder presents an internal cooling system using channels through which the fluid is forced to circulate internally, performing the heat exchange below the insert. The tool holder was used for both ambient, dry, and I.C.T.

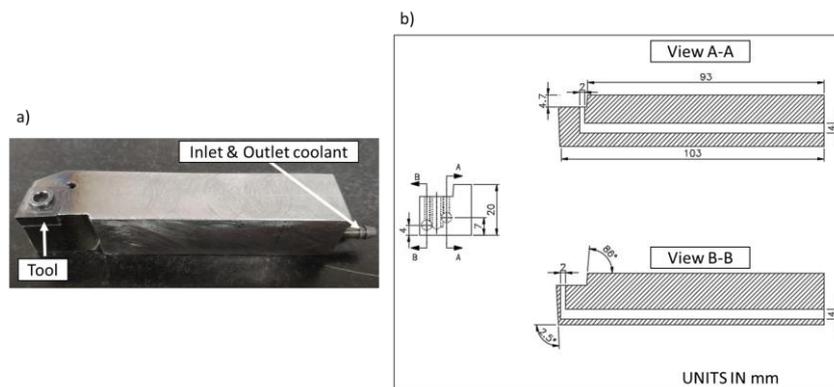


Figure 3. Designed tool holder by Figueiredo (2015): (a) real picture and (b) draws views

A cooling system was mounted and connected to the tool holder, as shown in Fig. 4. A mono ethylene glycol mixed with water (50%) at room temperature ($\sim 25^\circ\text{C}$) was used and stocked in a reservoir. A coolant pump circulated the coolant inside the tool holder using an inlet and outlet hoses system in a closed-loop removing heat below the insert during the cutting process.

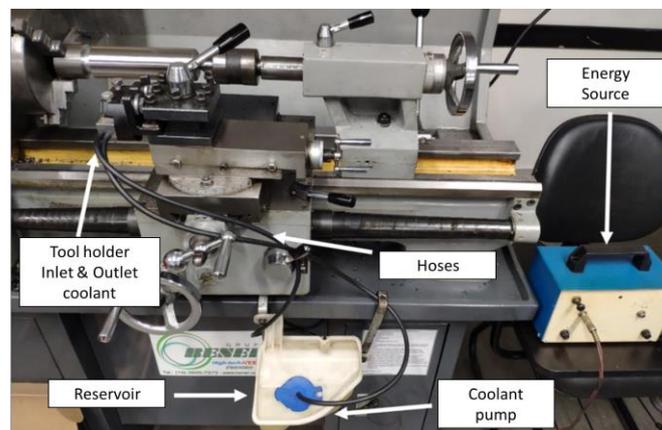


Figure 4. Designed cooling system with mono ethylene glycol

For all tests, the Mitsubishi manufacturer's tool, CCMT120404, was used, Fig. 5. Table 2 shows the insert data, as well as the cutting conditions indicated by the manufacturer.

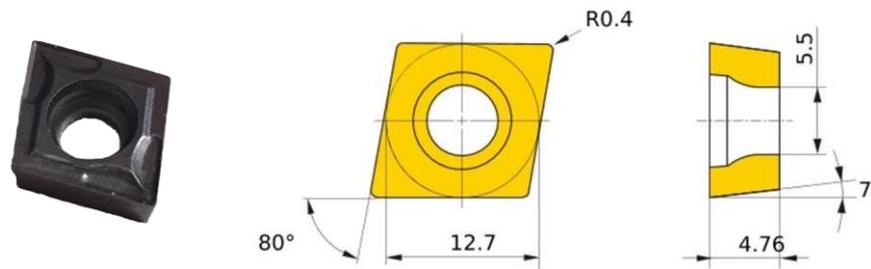


Figure 5. Mitsubishi CCMT120404 tool: (left) real picture; (right) drawing dimensions in mm

Table 2. Mitsubishi CCMT120404 datasheet

C	Insert form	Rhomboidal 80°
C	Clearance angle	7°
M	Tolerance Class (mm)	+ - 0,08
T	Fixing and/or output surface	With hole/ Unifacial chamfer
1 2	Insert size (mm)	12.7
0 4	Insert thickness (mm)	4.76
0 4	Nose radius (mm)	0.4
	Indicated feed (mm/rot)	0.20 to 0.50
	Cutting speed indicated (m/min)	105 to 150

2.2 ABNT 1045 Steel preparation

The steel billets ABNT 1045 were standardized in the measurements 100x100x100 mm for the procedure performed. Three samples were used.

Center hole for drilling was also performed in each specimen. Due to its relatively large length, the process vibration did not affect the workpiece roughness and altered the measurements. Figure 6 (b) is a representation of the dimensions of the specimens.

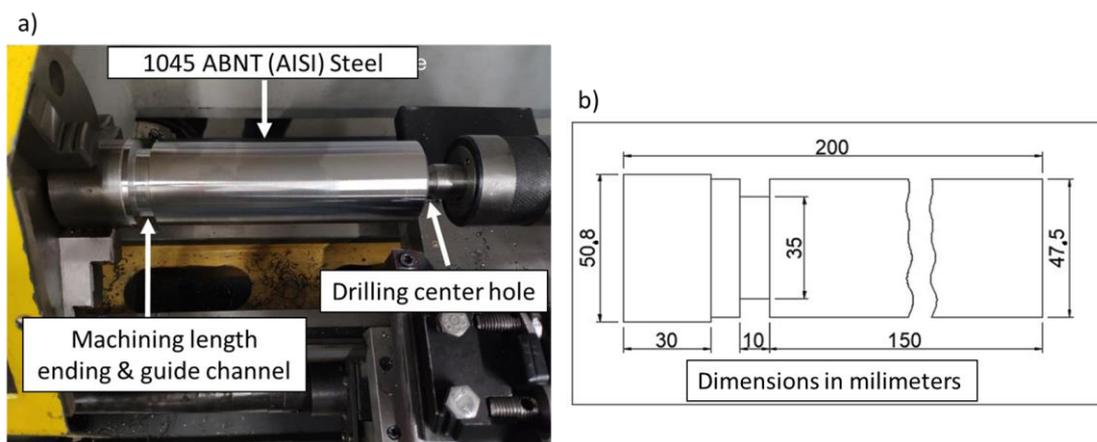


Figure 6. ABNT 1045 Steel: (a) Lathe mounted specimen and (b) specimen dimensions

2.3 Machining procedures

Evaluating tool wear and roughness, varying the ambient, dry, and I.C.T. machining, adopted the cutting parameters established in Table 3. It was used a lathe Vecker, model T.V.K.- 1224ECO.

Table 3. Cutting parameters adopted

Parameters	Values
V _c (m/min)	152 to 115
f (mm/rot)	0.40
doc (mm)	0.40
L (mm)	150
n (rpm)	1020
Ø (mm)	47.5 to 36

A Mitsubishi CCMT120404 tool insert was used for each process (dry and cooled), and each tool used two specimens, which start with an initial diameter of 47.5 mm and end with a final diameter of 36.0 mm. In total, 60 passes were performed in each process.

2.4 Measurement procedures

Roughness and wear measurements were made in a sequence of passes given in the specimen. Initially, it was made for every three passes, totaling six cycles. After, at every six passes, for more seven cycles, totaling thirteen measurement cycles. This change in intervals between measurements was performed because no significant wear was observed in the first seven cycles, so it was decided to increase the material removal rate and increase wear on the tool. Table 4 illustrates the procedure adopted.

Table 4 - Methodology adopted for measurements in dry and I.C.T. ambient

Specimen (1)(3)		Specimen (2)(4)	
Measurement	Passes	Measurement	Passes
1	3	9	3
2	6	10	4
3	9	11	4
4	1	12	5
5	1	13	6
6	1	Dry: Specimen (1) (2) ICT: Specimen (3) (4)	
7	2		
8	3		

The measuring procedures were made in the following way:

Roughness parameters: a Mitutoyo SJ-210 roughness meter, supported on a flat surface, was used. The ISO 4288 standard was adopted with a 2.5 mm cut-off (λ) ($2 < Ra < 10 \mu m$), sampling length x 5. Three measurements were taken varying the bar at 1200 ° for each section;

Tool's wear: a generic digital microscope with 200 x maximum magnification was used.

3. RESULTS & DISCUSSIONS

3.1 Roughness Analysis

Table 5 shows data on dry and I.C.T. testing, respectively, with overall average roughness, i.e., the average of all dry and I.C.T. machining measurements. Figure 7 demonstrates the behavior of the measured data. Using the results of Table 5., treatment was performed using statistical software to determine if differences exist between dry and I.C.T. average roughness (Ra). So, the following hypothesis in a ONE-WAY ANOVA analysis was made:

$$H_0: R_{aDRY} = R_{aICTH}, \text{roughness, for dry and ICTH are equal.}$$

$$H_1: R_{aDRY} \neq R_{aICTH}, \text{roughness, for dry and ICTH are different.}$$

The following assumptions were stated:

(i) The data represent six random samples from six normal populations;

(ii) $y_{ti} = \bar{y} + (\bar{y}_t - \bar{y}) + (y_{ti} - \bar{y}_t)$; where $i=1, 2, \dots, n_t$;

(iii) $\varepsilon_{ti} = y_{ti} - \hat{y}_{ti}$ and ε_{ti} are independent; identical and randomly distributed with $N(0, \sigma^2)$.

Table. 5 – Average and Standard deviation roughness (Ra) measurements for dry and I.C.T. ambient

	Dry			I.C.T.	I.C.T.		
	Measurement	Average	Standard		Measurement	Average	Standard
	1	5.911	0.081		1	6.459	0.094
	2	5.740	0.048		2	5.605	0.024
	3	5.814	0.057		3	6.315	0.042
	4	5.527	0.102		4	6.241	0.336
	5	4.879	0.193		5	4.835	0.049
	6	4.731	0.058		6	4.142	0.101
	7	5.417	0.107		7	4.865	0.056
	8	5.728	0.135		8	4.993	0.053
	9	5.100	0.089		9	7.494	0.067
	10	5.210	0.115		10	6.662	0.065
	11	5.586	0.056		11	7.069	0.650
	12	6.165	0.712		12	6.745	0.039
	13	6.567	0.166		13	6.751	0.090
	General	5.567	0.511		General	6.014	1.023

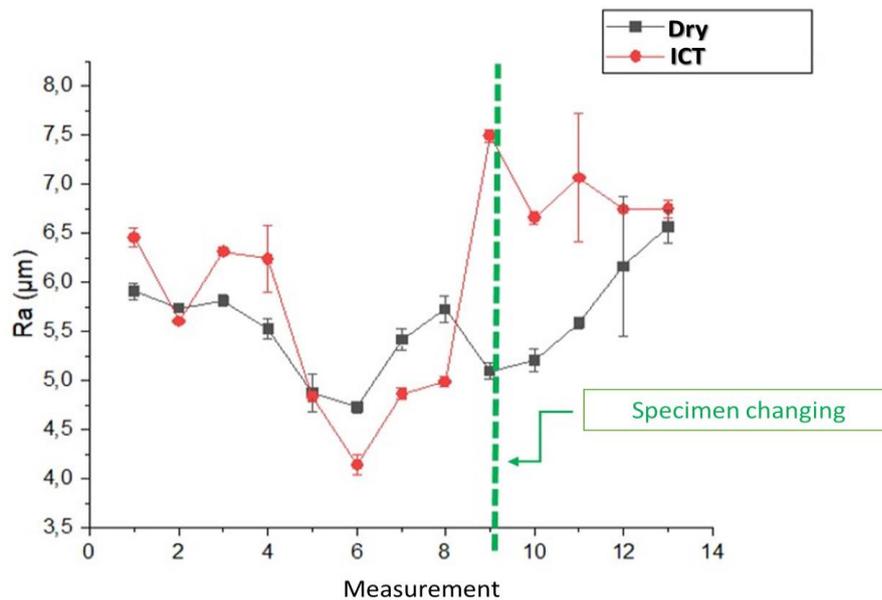


Figure 7. Roughness (Ra) measurements in dry and I.C.T. conditions

The one-way ANOVA results, computed for Table 5, were made considering 95% of reliability. Analyzing thirteen measurements of average roughness for each sample, the calculated P result was 0.1724. That is, the test confirms that dry and I.C.T. machining samples do not have statistically different means. It can be concluded that the use of I.C.T., under the process conditions, did not impact the finish of the machined part.

3.2 Tool's wear analysis

In the third measurement, microchips (circulated in highlight) were observed in the dry and I.C.T machining, Fig. 8. This type of wear is characteristic of the machining forces and the strength of the material. Therefore, it is believed that the difference observed is due to the microstructural characteristic of the insert. There was a dark region forming on the rake surface due to the temperature caused by chip sliding.

Figure 9 corresponds to the eighth measurement, where material adhesion in the cutting edge can be seen more clearly in both processes (marked in highlight). The adhesion and flank wear was higher in the dry machining process based on visual analysis, which was expected since higher temperatures favor this wear mechanism.

In the last measurement, that is, the 13th measurement, it was verified that there was no evolution of micro chippings, as already observed. The cutting edge used at the dry condition at the end of the process showed more significant deformation when compared to I.C.T., as indicated with the arrows in Fig. 10.

It was possible to notice that the cutting edges for the dry machining are bulging about the I.C.T. The more significant deformation in the cutting wedge may indicate greater flank wear since plastic deformation is the primary wear mechanism for flank wear.

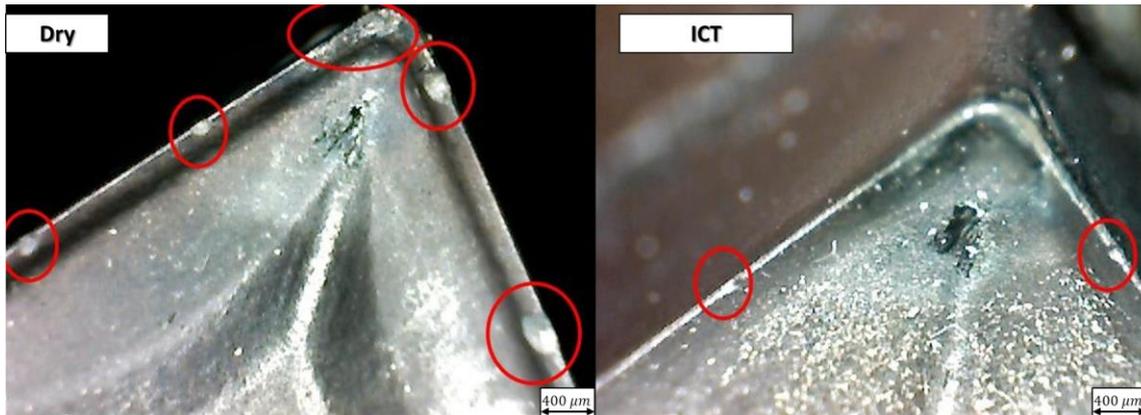


Figure 8. The third measurement indicating the presence of micro chippings for dry and I.C.T. ambient

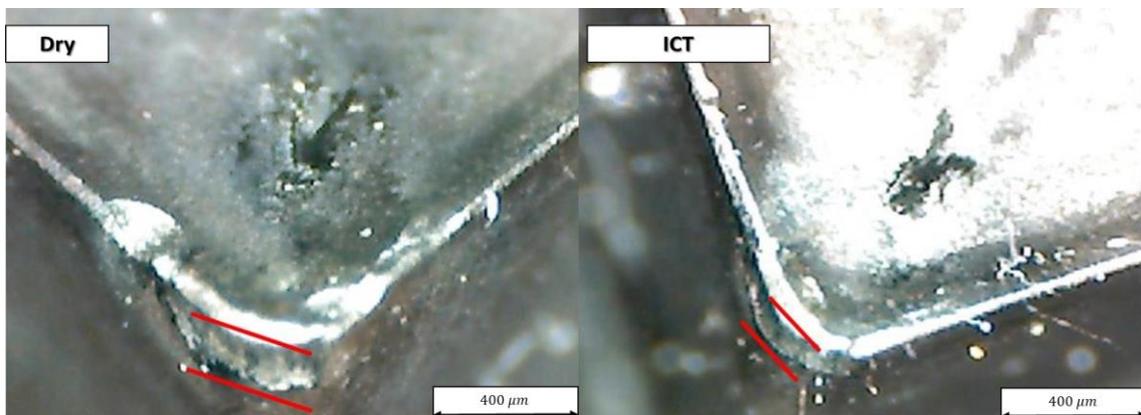


Figure 9. Eighth measurement indicating ABNT 1045 steel adhesion on the cutting edge

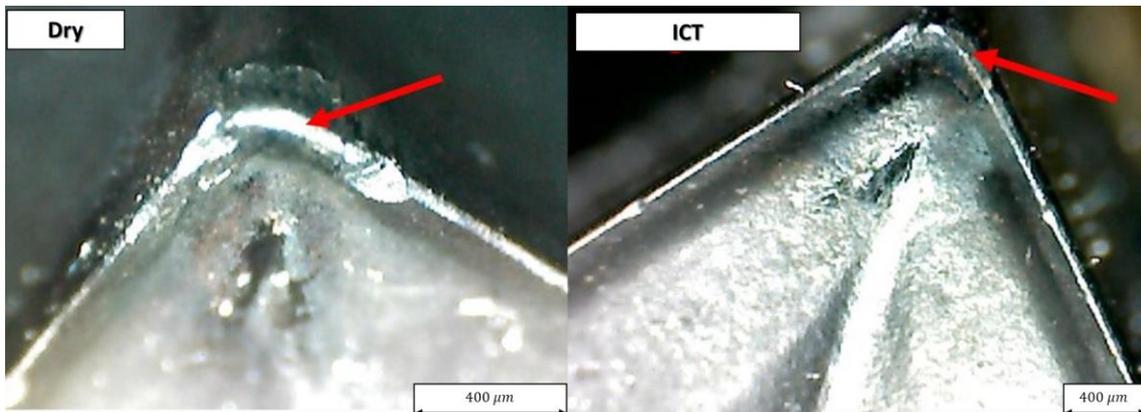


Figure 10. Thirteenth measurement indicating flank wear on the cutting edge for dry and ICT

4. CONCLUSIONS

This study aimed to compare two ambient, dry machining and I.C.T. Roughness and wear measurements were taken as response variables, and it was made in sequence of passes given in the specimen. Initially, it was made for every three passes, totaling six cycles. After six passes, for more seven cycles, totaling thirteen measurement cycles and sixty machining passes. The input variables were ambient (dry or I.C.T.), while the depth of cut (0,4 mm), rotation (1,020 rpm) and feed rate (0.40 mm/rev) were kept constant. The main conclusions indicate that:

- *Roughness (R_a) for dry and I.C.T. were statistically identical, showing that the proposed system did not act over part finishing, which can be considered as good, since an excellent cooling system must act only over the tool, preserving it and keeping the advantage of high temperature (material softening) in the piece;*

- *Tool's wear a 200 x magnification showed micro chippings, adhesion, plastic deformation (flank wear). In dry machining, all wear mechanisms were higher and much more evident in comparison to the I.C.T. This is a piece of evidence that the cooling system acted reducing tool temperature and avoiding its harmful effects and consequently preserving it;*
- *Finally, I.C.T. is a promising eco-friendly technique that acts only over the tool, keeping the sound effects of high temperature in the piece that softens the material easing the cutting process while cooling the tool preserving it. More studies are necessary, especially comparing it with C.F.A., also circumvent the lubricating lack.*

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