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ANALYSIS OF SURFACE ROUGHNESS WITH RESHARPENED TOOLS IN END MILLING OF VP20ISOF

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Abstract. *The main objective of the present work is to analyze of surface roughness produced by end milling with resharpened and coated tools. The process of regrinding allows the use of the same tool for a long time. When the cutting edge is damaged, it can be reground, thus performing the same service with the precision of a new tool. The machined surface roughness was analyzed throughout the lifetime of the tools. Cemented carbide end milling tools coated with TiAlN and AlCrN were tested as new and after they have been resharpened, during machining of VP20ISOF hardened steel, used in the mold and die industry. Tests were carried out dry and the cutting speed was varied, keeping the radial and axial depths of cut and the feed per tooth constants. A* 2^3 *factorial design was used, considering the following factors (and levels): cutting speed (80 and 100 m/min), tool coating (TiAlN and AlCrN) and the tool condition (new and reground). The results showed that in general the AlCrN coated tools outperformed the TiAlN. The surface roughness of resharpened tools was very similar to the new tools, and statistically there is no significant difference between them.*

Keywords: *surface roughness, end milling of hardened steel, coated carbide tools, resharpened tools.*

1. INTRODUCTION

Currently, the industry is increasingly thinking in obtaining products with high quality, low production cost and high productivity (Moura, 2012). The machining plays fundamental role in the manufacturing processes of the most diverse areas of mechanical engineering. Among the several machining processes milling constitutes one of the most important for productivity and flexibility (Groover, 2002).

The machinability and the machined surface are critical in the process of manufacturing molds and dies, representing most of the total cost. Molds for plastic processing have long service life, in some cases more than ten years, and the most important properties are related to the processing characteristics such as polishability, machinability, and response to heat treatment. The significant volume of material removed when making the mold makes the machinability of the steel used very important, which depends on metallurgical factors and machining conditions, such as tool type and cutting conditions (Castro, 2010).

One fraction of the machining costs involves the tool price divided by numbers of parts that can be produced with it, thus, many researchers focus their work on aiming to improve the tool life and consequently adding value to the tool (Suarez et al., 2009). The concern of the mold and die sector with the concept of cost reduction is not different from other industries.

To meet this reduction, the companies need to invest in powerful software and hardware tools, CNC machines more fast and rigid, modern tools concepts, tool materials and coatings with adequate tribological behavior for each specific application. (Ribeiro et. al., 2009).

The cost of a tool is calculated not only by the purchase price of the insert, but also involves consideration of the number of pieces that can be produced with it.

The use of resharpened tools provides reduction in machining cost and prolongs the use of a tool in a certain process. In production lines is something that has gained strength over the years, especially with the market introduction of specialized companies in this segment, but in contrast with sparse literature and scientific papers that show the performance of these tools. The present paper intends to contribute with the literature in this area, investigating the performance of new and resharpened tools when end milling VP20ISOF steels, concerning to the surface quality produced. This is part of a larger research (MOURA, 2012) that besides surface roughness has considered other output variables, such as tool life (wear rate), cutting forces and torque.

2. EXPERIMENTAL PROCEDURES

The machining tests were carried out at the Laboratory for Teaching and Research in Machining – LEPU of Federal University of Uberlandia, MG – Brazil using a Romi/Bridgeport Discovery 760Machining Center, CNC Siemens 810, 15kVA (spindle speed range of 10 to10,000 rpm).

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The end milling type chosen was the up milling with constant radial depth of cut (a_e) of 1 mm, axial depth of cut (a_p) of 10 mm, feed per tooth of 0.015 mm/tooth and cutting speeds: v_c= 80 and 100 m/min. The tool overhanging length was 35 mm and the radial and longitudinal deviations at the tool tip when rotating the tool was 6 µm and 9 µm, respectively.

The end of tool life criterion used was recommended by the tool manufacturer, VB_B = 0.2 mm, value established to ensure that the milling tool could be reground at least five times without losing much of its final diameter, since the regrind is performed in the radial direction of the tool. After reaching their end of life the tools were sent back to the Regrinding Tool Centre of OSG Sulamericana Ltda. for resharpening and then to Oerlikon Balzers for recoating, before being returned to LEPU - UFU for new machining tests.

All the tests were performed dry and interruptions for tool wear measurements vary from 10 to 20 passes, depending on the cutting condition and tool coating used. They are all long time tests, as shown in Tab. 1. The time presented there is the cutting time, calculated based on the feed velocity and the total cutting length until the end of the tool life. Surface roughness was measured throughout the tool life tests, every time the tests were stopped for tool wear measurements, using a Mitutoyo SJ-201 surface roughness meter.

Table 1 – Machine times for the tests.

Cutting Speed (v_c)	**Average tool lifetime**	
	AlCrN	**TiAlN**
80 m/min	8h 45min *approx. 200 passes* *VB_B = 0.2 mm*	5h 50min *approx. 140 passes* *VB_B = 0.2mm*
100 m/min	4h 40min *140 passes*	3h 20min *100 passes*

Average flank wear, VB_B, according to ISO 8688-2 (1989) was measured throughout the extension of the leading edge of 10mm, corresponding to the depth of cut used. An Olympus SZ61 optical microscope was used for this purpose.

The cutting speeds (v_c=80m/min and v_c=100m/ min) were determined after some pre-tests and based on recommendation of the toll manufacturer's catalogue (OSG, 2010), with constant radial depth of cut (a_e) of 1 mm, axial depth of cut (a_p) of 10 mm, feed per tooth of 0.015 mm/tooth. These cutting speeds promote uniform wear on the tool as shown in Fig. 1a, reducing the chance of chipping, frequently observed when using lower cutting speeds (Fig. 1b). For the higher cutting speed of v_c=100 m / min, the end of life criteria had to be changed due to increasing vibration as the wear approaches the limit of VB_B=0.2 mm. A fixed number of cutting passes was adopted instead. A pass means a cutting length of 360mm as illustrated in Fig. 2. Table 2 shows the end of tool life criteria adopted for each type of test. Tools coated with AlCrN presented higher wear resistance; therefore, the number of passes stipulated for them is also higher.

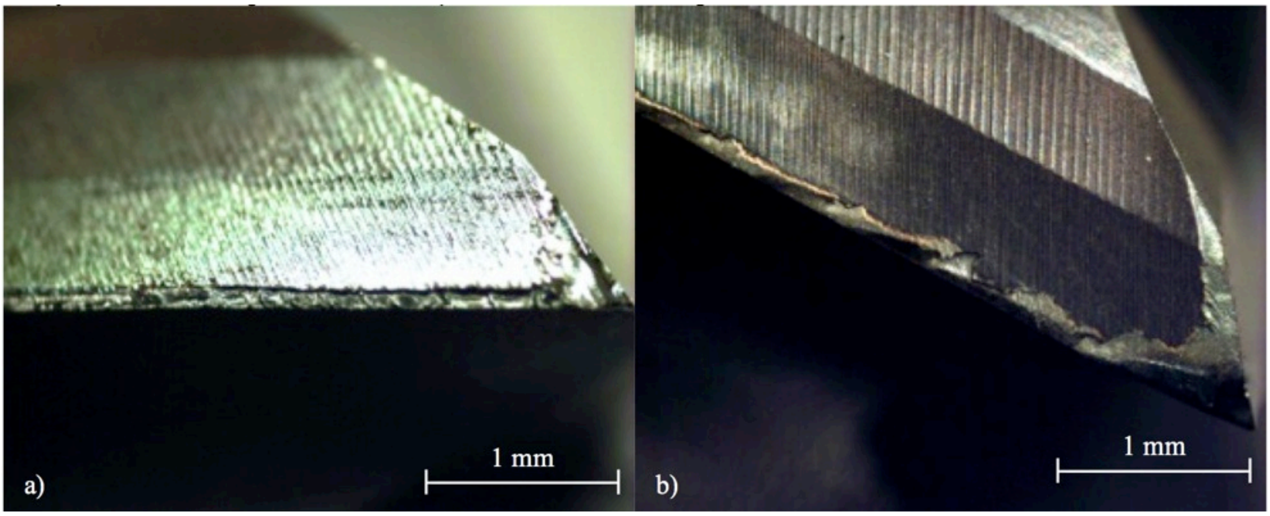

Figure 1 - End milling tools: v_c=100m/min, f_z = 0.015 mm/tooth, VB_B = 0.2 mm (a); v_c=50m/min, f_z = 0.015 mm/tooth, VB_B = 0.2 mm (b).

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Figure 2 – Cutting length (Pass).

Table 2 – End of tool life criteria.

TEST	v_c*(m/min)*	v_f*(mm/min)*	f_z*(mm/tooth)*	**End of life criteria**
Type 1	80	153	0.015	VB_B=0.2 mm
Type 2	100	191	0.015	100 passes - TiAlN 140 passes - AlCrN

The surface roughness of the AlCrN coated tools can be measured up to about passed to the 180th in test Type 1 (v_c=80m/min), passing this value was the tendency of adhesion under the chip surface and the workpiece can be seen in Fig. 3 which details the evolution of this trend adhesion on the surface of the chip. This membership was probably due to the high temperatures generated and the natural wear of the lining of the tool. For condition 2 (v_c=100m/min), there was no adhesion of chip on the machined surface. The impression one gets is that the tool to achieve a high value of wear, stuff starts to tear rather than cut, leaving burrs on the machined surface. Remembering that this is the main surface machining.

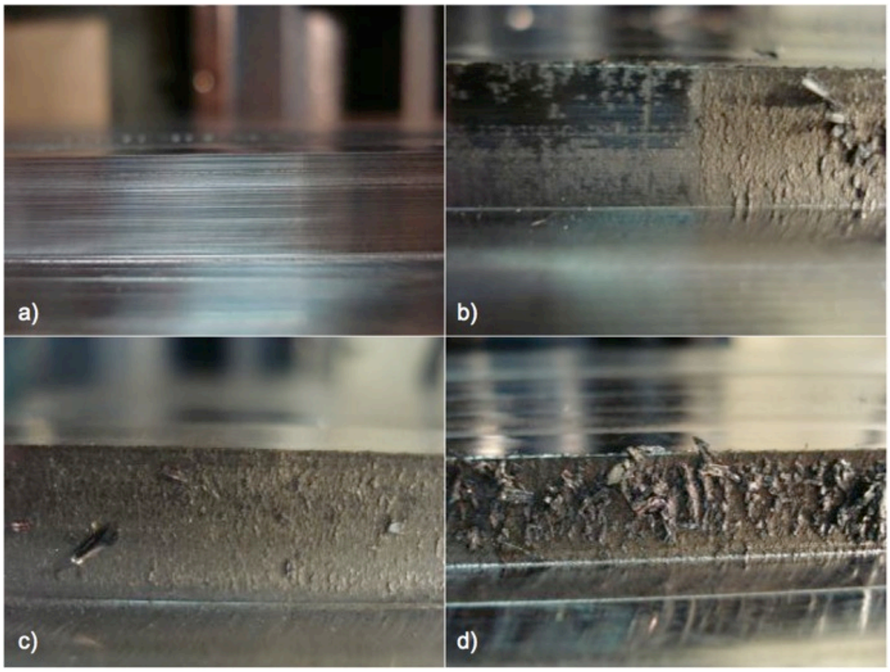

Figure 3 - Machined surface to AlCrN, v_c=80m/min (a) new tool, (b) tool life of approximately 80%, (c) between 90% - 95% of life, (d) end of life and 100% (200th pass).

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The sampling length is defined by the ISO 4287 (2002) standard as being the length in the X-axis direction used to identify the characteristics of the profile irregularities under evaluation. The evaluation length may contain one or more sampling lengths and is used to determine the profile to be evaluated. It is used usually an evaluation length equivalent to five times the sampling.

2.1 Workpiece material – VP20ISOF

The workpiece material machined was the ABNT P20 steel (the same designation of ASTM, SAE, AISI and WNr-DIN 1.2311), one of the steels most used for plastic injection molds. It was provided in the prismatic form, with dimensions of 190x250x360 mm^3, manufactured by Villares Metals S/A (Böller Uddeholm Group) with the commercial name of VP20ISOF. This is a Cr-Mo steel produced through vacuum degasification with improved machinability by calcium treatment in the quenched and tempered condition. Its hardness is in the range of 30-34 HRC (302-336 HV). The hardness of the sample used in the present investigation was 32.7 HRC. This steel has good polishability, texturing and is a variation of the common VP20ISO. The main difference between them is the absence of nickel in the VP20ISOF what results in lower production cost. Table 3 shows the chemical composition of the steel.

Table 3 - Chemical composition of VP20ISOF

C	Mn	Si	Cr	Mo	P	Al	Ca	Fe
0.30	1.60	0.27	1.80	0.20	0.013	0.016	19 ppm	Bal.

The VP20ISOF steel was developed to have high machinability without loss in its polishability, being produced with low sulfur and submitted to a treatment with calcium for secondary refining and modification of oxide inclusions. The steel treated with calcium provides an improved machinability through a control of the morphology of hard inclusions like alumina and silicates improving the tribological conditions of the chip-tool interface during machining, thus reducing tool wear at high cutting speeds. The deoxidation with calcium does not alter the mechanical properties or affect the thermal treatment response consequently its hardness for example (Milan et al., 2000).

In his research, Milan (1999) noted that the protective layer is formed in the chip-tool and workpiece-tool interfaces during the machining process. Because of the high temperatures developed there, the calcium oxides are soft on the surface of the tool and allow reduction of wear. Calcium acts altering the oxide inclusions and usually these new oxides (Al_2O_3 + CaO) are enveloped by manganese and/or calcium sulphides, so that they remain in the viscous state at high temperatures with lower shearing strength (Evangelista and Machado, 2008). Microstructural analysis also showed the presence of manganese sulfides, evidenced by Milan (1999) through an analysis using WDS, as seen in Fig. 4, that also has an important role at the chip – tool interface.

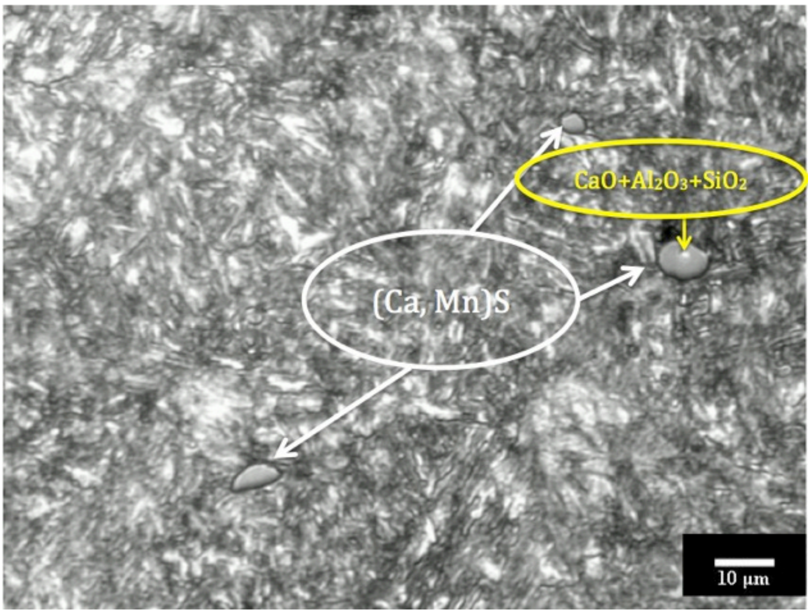

Figure 4 – Microstructural analysis (presence of (Ca, Mn)S in VP20ISOF).

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2.2 End milling tools

H10 carbide end milling tools, with 10% of cobalt, HY- PRO® series with 4 teeth, manufactured by OSG Sulamericana Ltda, were used in the tests. Two different types of PVD coatings by Oerlikon Balzers, ALCRONA® (Al-Cr-N) and Futura Top® (Ti-Al-N) were tested and their characteristics are described in Table 4.

The cylindrical tools have 10 mm of diameter, 70 mm of total length, and 25 mm of cutting edges, as shown in Fig. 5. A total of 24 tools were tested, 12 of each coating.

Table 4 – Coating properties.

Propriety	**AlCrN**	**TiAlN**
Microhardness (HV 0.05)	3200	3300
Coefficient of friction against steel	0.35	0.25
Maximum operating temperature (°C)	1.100	900
Color	Blue-gray	Violet-gray
Commercial Name	ALCRONA®	FUTURA TOP®

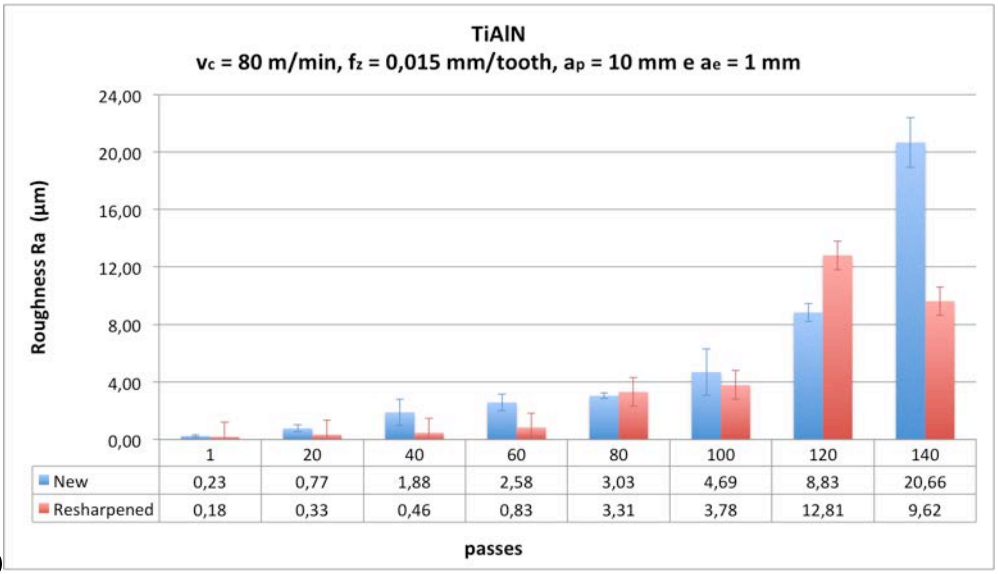
Figure 5 – End milling tools.

2.3 Regrinding process

The regrinding process was performed at the Regrinding Tool Centre of OSG Sulamericana Ltda. The process reproduces the entire geometry of the tool through the same machining process used when firstly manufacturing the tools, using an abrasive wheel tool. Further information of the process was not given by the manufacturer due to commercial protective reasons. After reground, the tools were sent to Oerlikon Balzers, where they received new coatings. The coating can be made over the previous coating or removing the old coating (by etching) and applying a new one. In the present work the coating was applied without removing the previous one. The process of PVD was applied maintaining the coating thickness between 0.002 and 0.005 mm. Each coating tool received a number varying from 1 to 12 to identifying them.

3. RESULTS

Fig. 6 and 7 show the surface roughness value throughout the life of the tools coated with TiAlN in the form of graphs comparing the surface roughness of the new and resharpened tools. One can observe that with increasing cutting speed the surface roughness tend to decrease, which is justified by the increase in cutting temperature, which decreases the shearing strength of the workpiece material, promoting the reduction of the machining forces and consequently improving the surface finish. The surface roughness values tend to increase over the life of the tool due to the natural wear of the cutting edge during the machining process. It was also observed that the surfaces roughness generated by new and reground tools in early life are similar. However, with the development of wear, the measured values of surface roughness are different for the both tools. In many wear tracks of the reground tools presented smaller surface roughness than the new tools, possibly the format of your wear are influencing these results.



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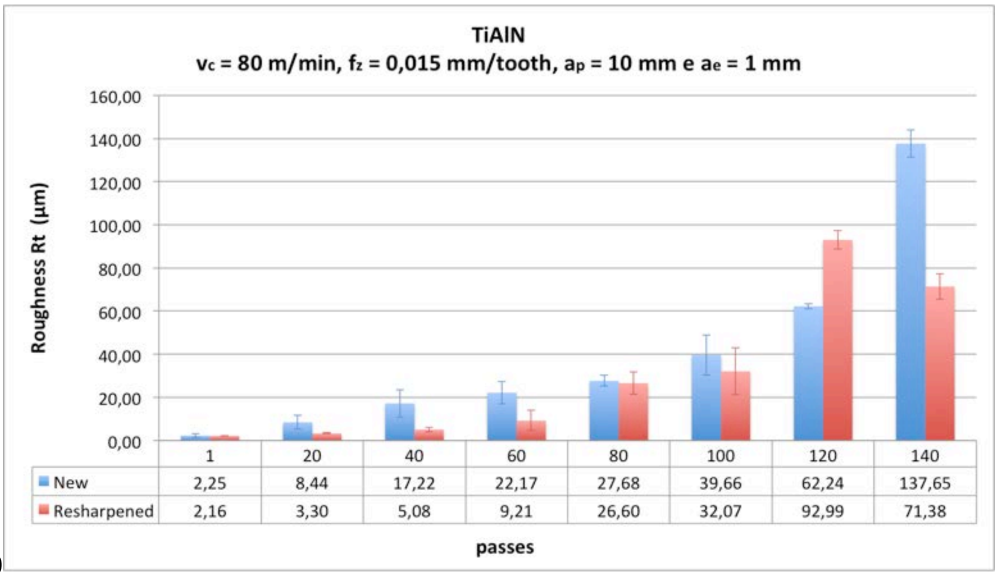

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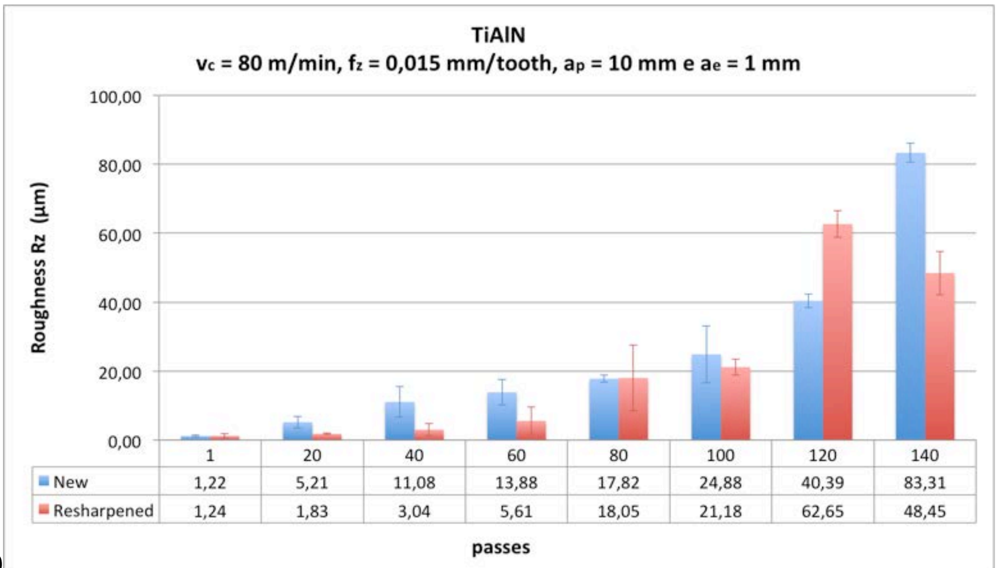

c)

Figure 6 – Surface roughness for TiAlN, v_c=80m/min, R_a (a), R_t (b) e R_z (c).

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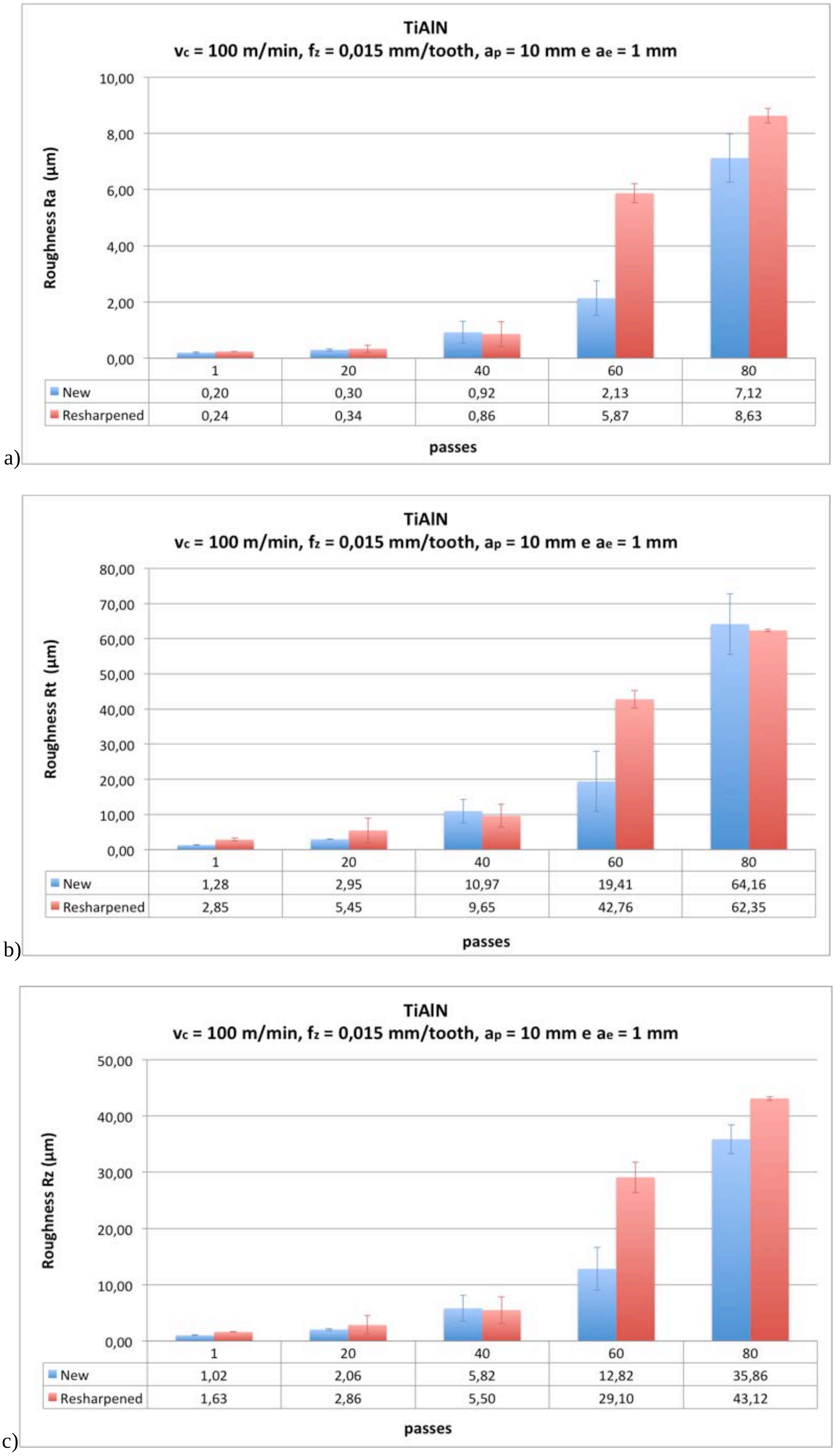


Figure 7 – Surface roughness for TiAlN, v_c=100m/min, R_a (a), R_t (b) e R_z (c).

Surface roughness measurements in the end milling operation are not always consistent with the results reported in the literature about specific machining. In certain cases occur results that intrigue those who study this phenomenon. At the beginning of the end milling process, even with new tools, the wear of the cutting edge has a tendency to evolve and achieve certain dimensions and shapes that accelerate the its own process of wear, impairing the quality of the surface that is machined. However, at certain moments, the wear can produce the cutting edge shape that resembling the wiper edge, thus generating better finished surfaces. Although, with continuous increasing of the wear, the finished surface tends deteriorate again (PEREIRA, 2006; MOURA, 2012).

For TiAlN with cutting speed of 80 m/min was found that the surface roughness measure for parameters Ra, Rt and Rz resharpened tools was lower at the end of life than the values in the 120th pass, showed in Fig 6, which can be explained by adherent material generated at the end of life in some tests with reground tools, as shown in Fig. 8.

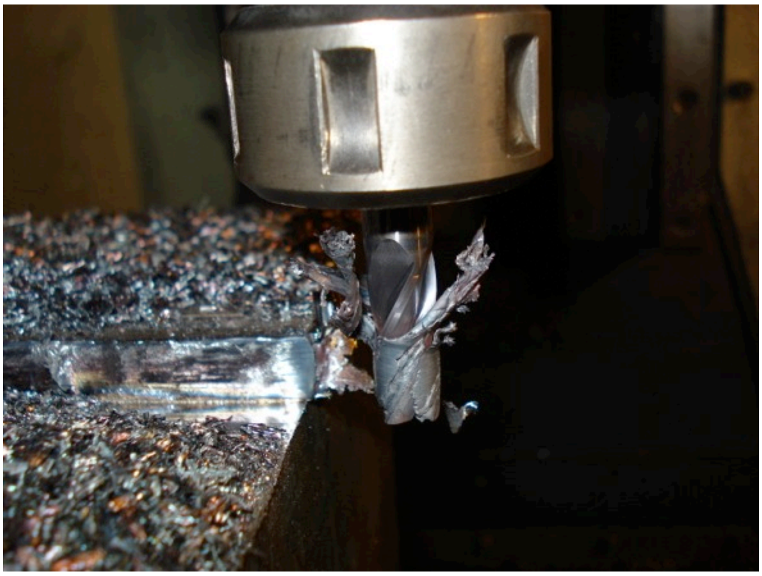


Figure 8 - Pasting at the end of life with TiAlN reground tool, v_c = 80m/min.

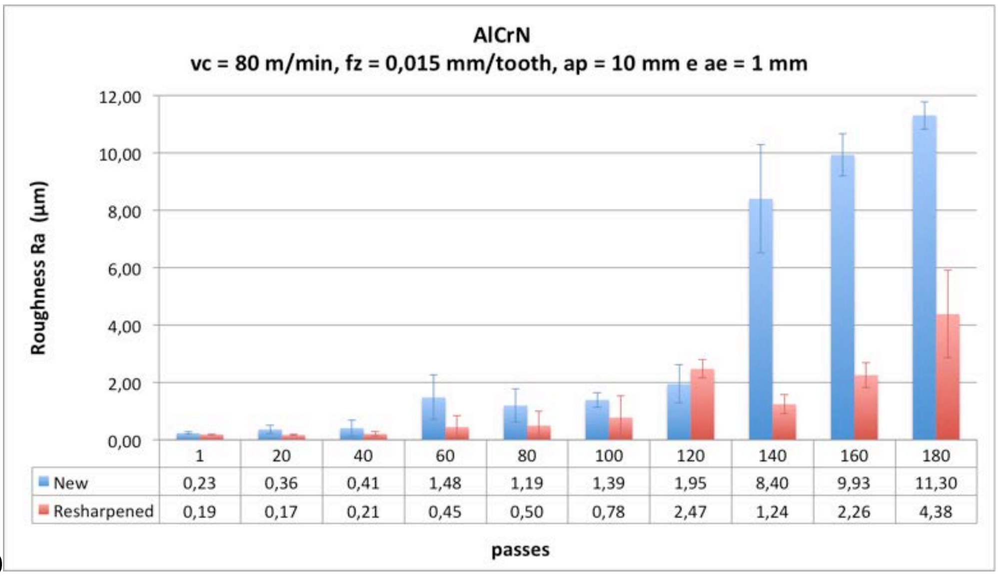
Fig. 9 and 10 show the surface roughness values throughout the life of the tool AlCrN coated in the form of graphs comparing the surface roughness of the new and reground tools. One can see here the same behavior of the TiAlN tools with respect to the influence of cutting speed (higher speed generates better finishes) and the growth of the surface roughness with the wear. Furthermore, the behavior of the surface roughness generated by new and reground tools. At the beginning of the tests there is no difference between them, but with the wear of the tool there is the tendency reground generate better finishes indicating that the format of wear are important factors in the generation of surfaces.

To analyze the behavior of the tools with statistic reliability a factorial design 2^k classic was used, with 2 levels (new and reground tools) and 3 factors (cutting speed, coating and regrinding), generating a 2^3 factorial design for 95% of reliability. The comparisons were performed with surface roughness values early in life (with the aim of eliminate the influence of wear on the surface roughness parameters) and the 80th pass. Pareto charts allow to analyzing the influence of one or more parameters and their interactions simultaneously in surface roughness as shown in Fig. 11.

The AlCrN coated tools showed better surface finish when compared with TiAlN in 80th pass, which can be explained by the lower wear generated in the AlCrN coated tools, which contributes to the coating is the most influential factor in the Pareto chart. The surface roughness values decreased with increasing of the cutting speed, for the same cutting speed was a tendency of increased surface roughness over the life of the tool, which can be explained by the gradual increase of the wear generated throughout life.

Recent work (Sousa, 2011), were tested staggered carbide drills, new and reground, uncoated and coated with TiAlN and AlCrN in the drilling process 19MnCr5G steel (AISI 5115). In this case, the reground tools showed higher wear rates (on average 33.85%) compared with the new tools. The reground tools showed an increase in surface roughness values Ra, Rz and Rt compared to new tools (on average 20.18%, 25.64% and 21.93%, respectively). The TiAlN reground tools presented higher surface roughness (on average 38,53%, 66,51% and 72,57%, respectively) while the AlCrN reground tools presented smaller values (on average 27,79%, 46,43% and 40,97%, respectively).

The accomplished work by Sousa (2011) and this present work show that the main influence factor of the surface roughness was the type of coating. The interaction between the cutting speed and the type of coating (shown in Fig. 11b, d and f) was the second most influential factor.



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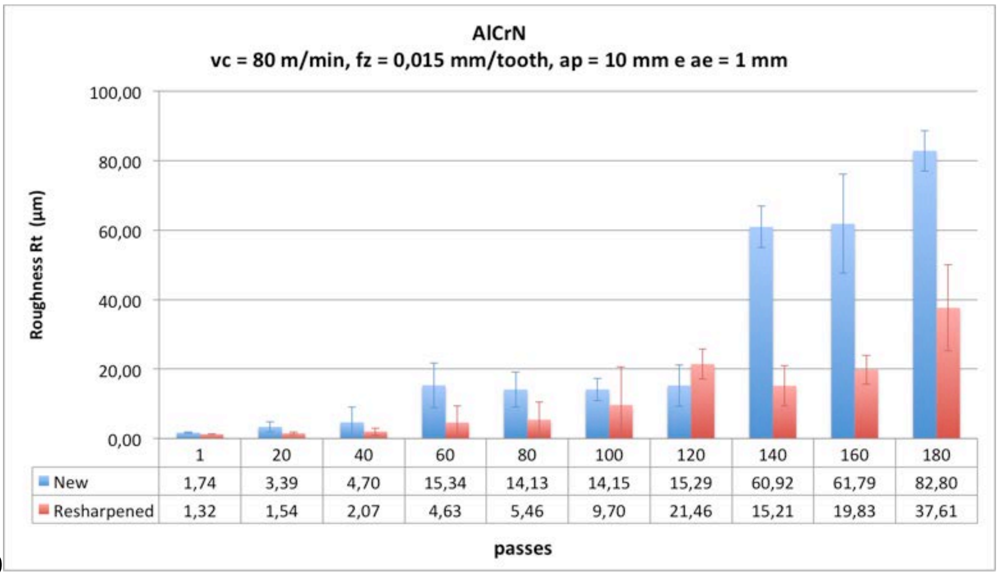

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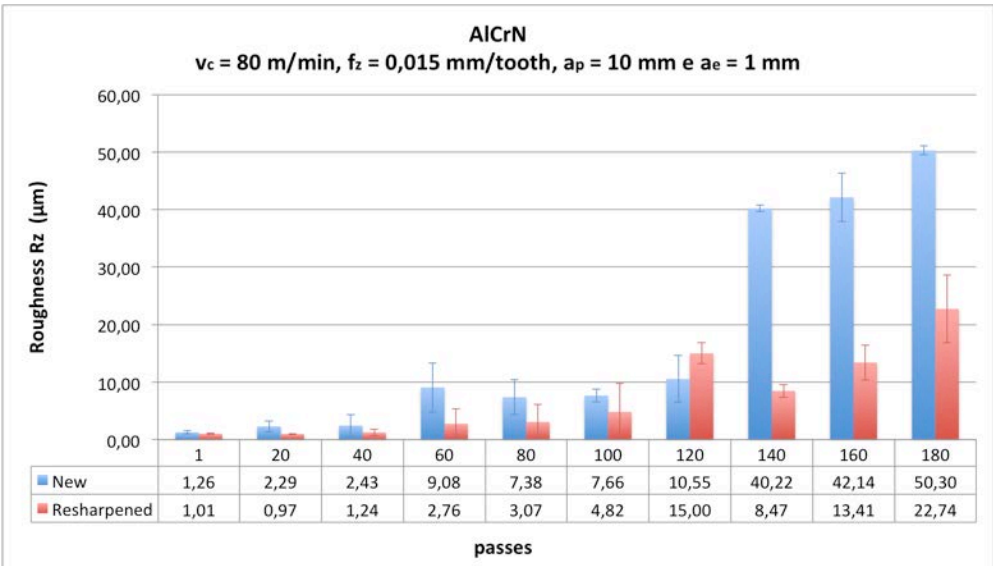

c)

Figure 9 – Surface roughness for AlCrN, v_c=80m/min, R_a (a), R_t (b) e R_z (c).

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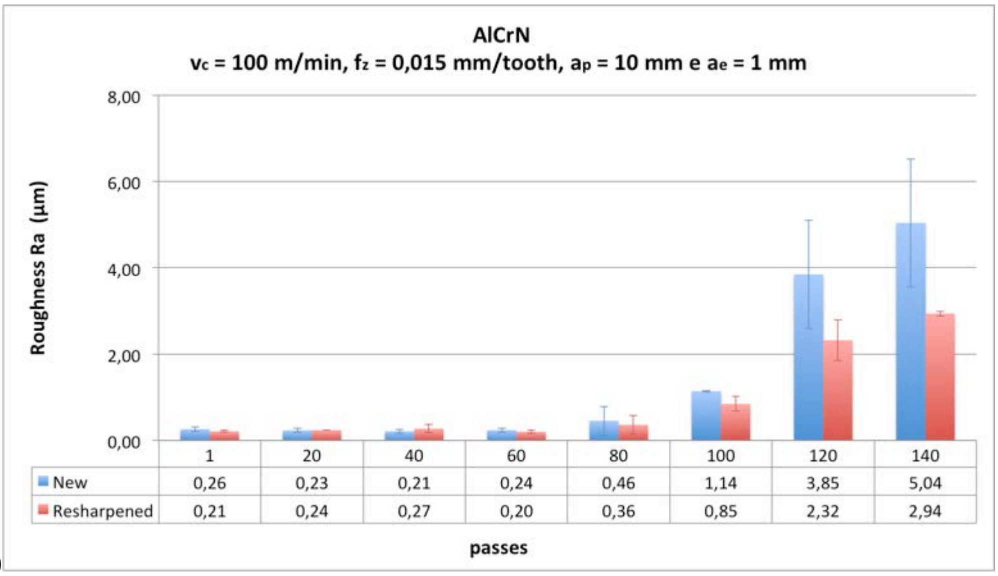

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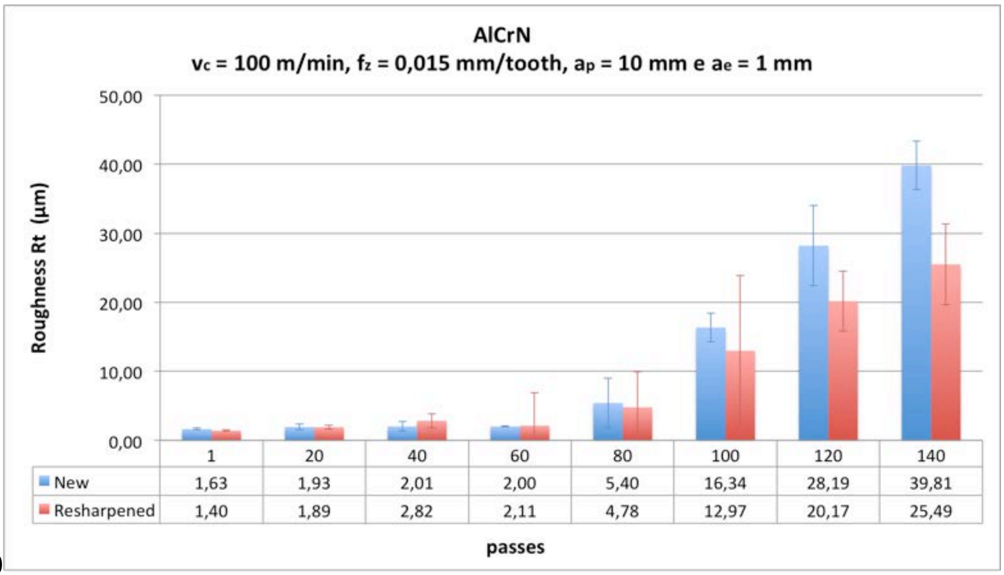

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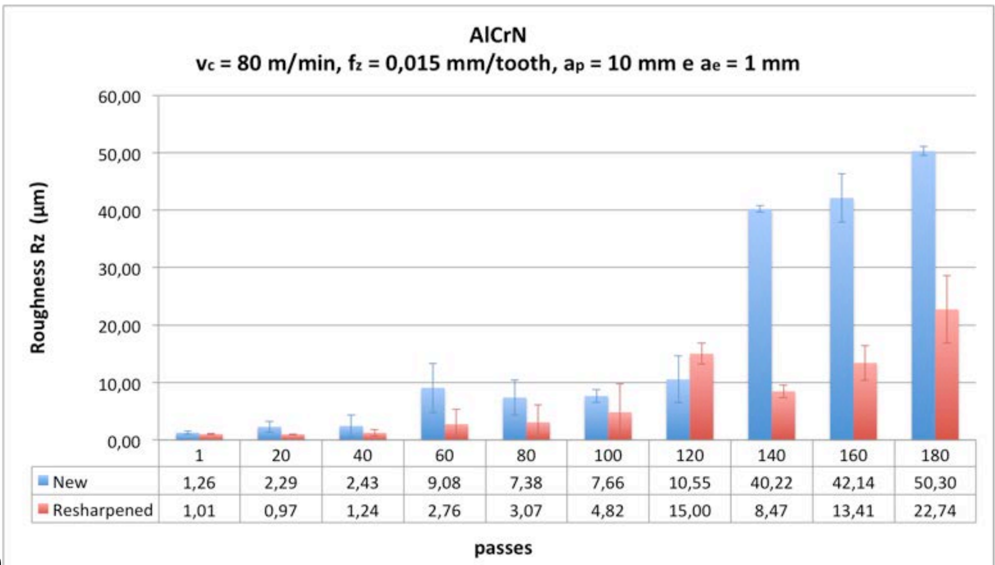

c)

Figure 10 – Surface roughness for AlCrN, v_c=100m/min, R_a (a), R_t (b) e R_z (c).

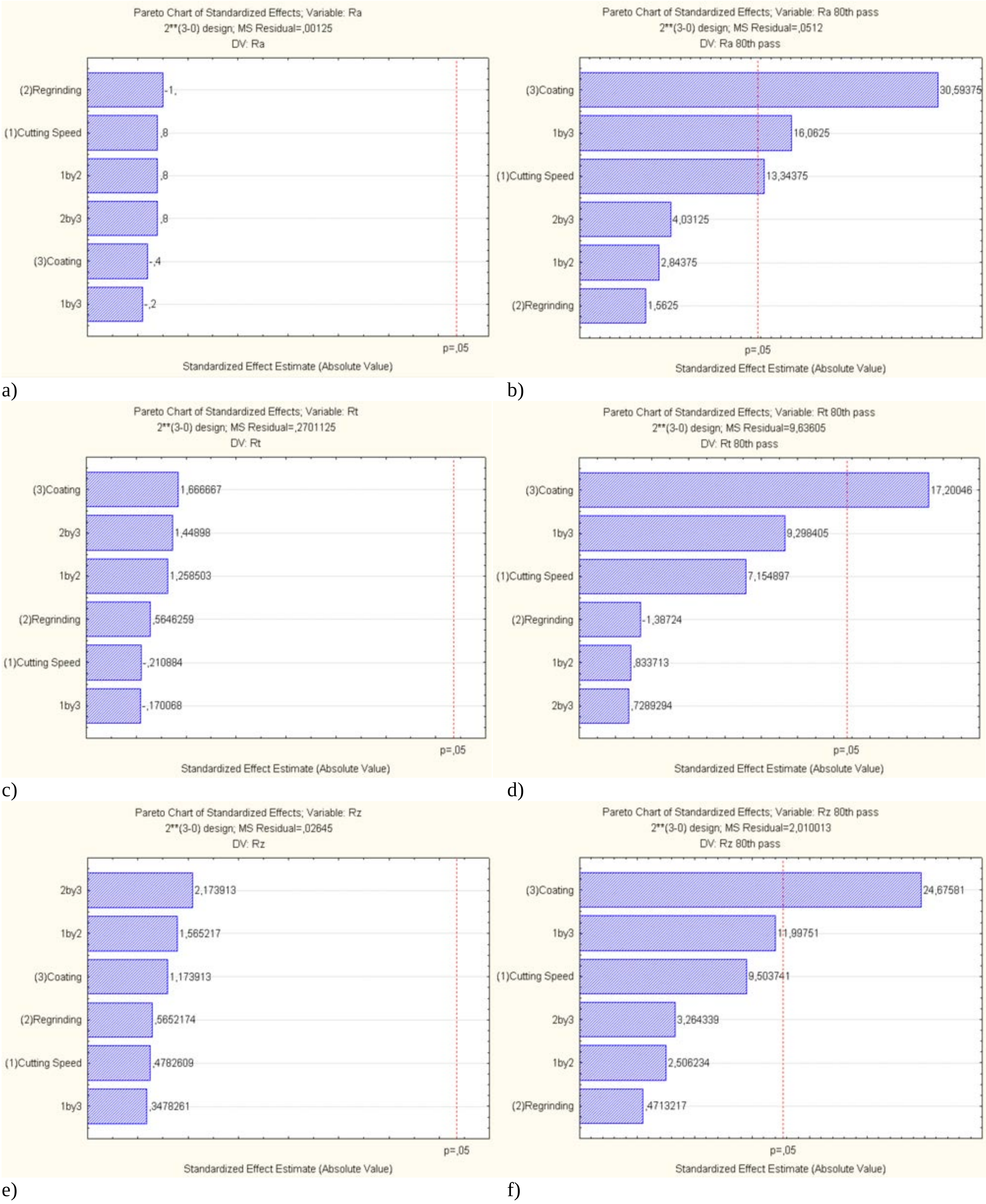

Figure 11 – Pareto chart: R_a (a), R_a 80th (b), R_t (c), R_t 80^{th} (d), R_z (e), R_z 80^{th} (f).

4. CONCLUSION

The results presented allow the following conclusions to be drawn:

- ✓ The surface roughness values increased throughout life of the tool, which is justified by the increased wear.
- ✓ The AlCrN coating tools obtained better results of surface roughness compared with TiAlN.
- ✓ For cutting speed of 80 m/min with both coatings, reground tool showed better surface roughness than the new tool.
- ✓ With increasing cutting speed (100 m/min), reground coated tools with TiAlN had a worse surface roughness when compared with the new tool.

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- ✓ The reground and coated tools with AlCrN obtained a surface roughness better than the new tool for two values of cutting speed adopted.
- ✓ Statistical analysis showed that the data for the surface roughness using new or reground tools was not significant for a reliability of 95%, confirming that the coated reground tools has a similar performance to the a new tools.

5. ACKNOWLEDGEMENTS

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