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STUDY OF ROUGHNESS IN TOOLS WITH INTERNAL COOLING CHANNELS
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Abstract. *Due to the industrial competition to product fabrication with a low cost and low time, more and more, the environment has been degraded, not only by natural resources extracting, but also by the polluting means. As a way to alleviate this problem, the governments have been created laws compelling the industries to work in a search for less harmful solutions to the environment through "green methods". On the research side, several works are been carried out proposing techniques that minimize the pollution problem caused by industries today. In this work, a study about roughness regarding an alternative technology is proposed. This technology is based on tools cooled internally modified by channels insertion where a coolant fluid circulates, cooling it during the machining process. The proposed cooling system has a main objective to exclude or minimize the cooling fluid application, which is one of the main factors in machining pollution. This work proposes to analyze the influence of this system on the roughness of the piece comparing with dry cut. To check this effect, turning tests were performed on cast gray iron where the cutting speed parameter was varying in three levels, maintaining the feed and depth of cut constants. As a result, it was noticed that the use of cooled tools does not influence significantly in roughness.*

Keywords: *cutting tools, roughness, sustainability, internal cooled tools.*

1. INTRODUCTION

According to Machado *et al.* (2015), the roughness of a surface is composed of fine irregularities or micro-geometric errors that are derived from a cutting process, through the feed marks, tool wear and cutting insert edge. In many cases, roughness is used as an output parameter to control a machining process, being a strong indicator of the part's finish. According to (ABNT NBR ISO 4287, 2002), the roughness profile and its parameters are the only parts of the surface roughness characterization that are historically well defined.

Studies such as the one by Kumar *et al.* (2012) state that theoretically roughness increases with increasing cutting feed and decreases with the increase of tool tip radius, since the surface finish is influenced by the movement of the tool around the part, producing parallel grooves in the direction of cutting speed. Thus, the greater the feed or the smaller tool nose radius, the greater the distance between the grooves and the greater the profile height. According to (Machado et al., 2015) there are other parameters that influence the roughness of the material, which are: the rake angle of the tool, rigidity and precision of the machine, the flexural strength of the billet, cutting edge wear and the application of cutting fluids. At high cutting speeds the use of cutting fluids can worsen the finish, as cooling increases the cutting forces, however at low speeds lubrication can be beneficial to the surface finish (Santos and Sales, 2007).

Thus, in order to study the effect of coolant on surface finish, in this work a study was carried out on the turning of gray cast iron through an alternative machining coolant system, which is based on internally cooled tools in a closed system. This system was studied by (Bazon, 2020), (França, 2021) and (Barbosa, 2021) and was called by Internal Cooled Tool (ICT). The main objective of this work was to study whether the internal cooling of cutting tools significantly influences the surface finish of the material.

2. INTERNAL COOLED SYSTEM

2.1 Cooling and Machining Subsystems

Next to a conventional cooling system, this system is divided into 2 subsystems (Figure 1), the machining, on the left of the dashed line in green, and on the right, the cooling. In this cycle, what connects one subsystem to another are the hoses that circulate the fluid that cools the tool. The main purpose of the cooling subsystem is to cool a secondary fluid that will serve as a refrigerant for the machining subsystem.

The cooling subsystem used was a conventional cooling system, composed of the expansion device, condenser, compressor and evaporator. The evaporator is a reservoir that serves as a cooler for a secondary fluid, which in this case was mineral water. The water, when cooled in the reservoir, goes to the machining subsystem, to the left of the green line, circulating through the modified tool holder, clamp and tool, leaving the bottom of the tool holder and returning to the reservoir.

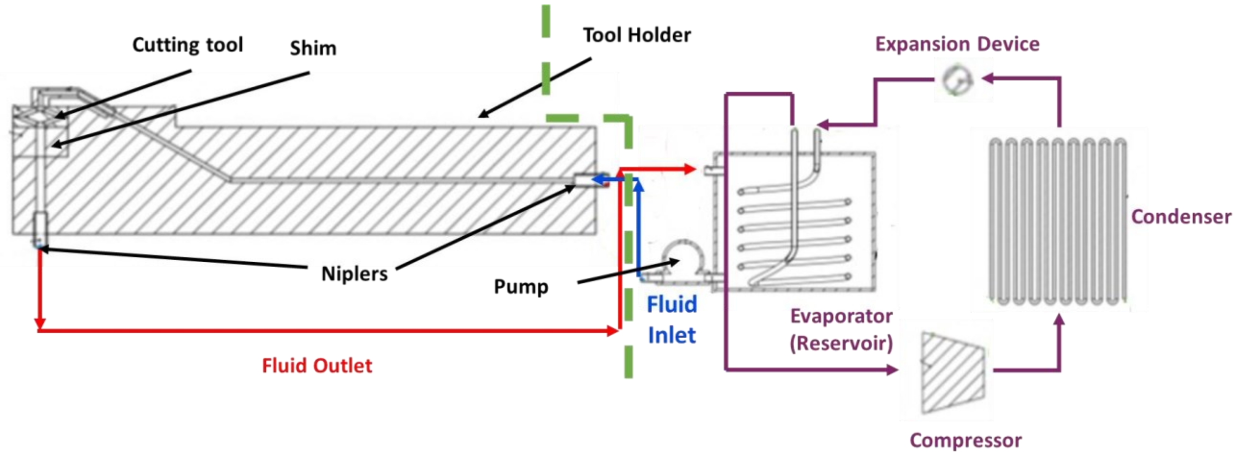

Figure 1. Machining and cooling subsystems.

2.2 Tool holder and modified tool

For the tests, the cutting tools used are Seco Tools® model SNUN120412, where the internal coolant channels of the tools were manufactured through the process of electro-erosion by a rotating electrode, and covered with silver solder. The Figure 2 shows a computer-aided design drawing of the modified tools indicating the way of the water flux inside of the tool. The water enters in the hole located at superior face, circulating inside of your body through internal channels and leaving in another hole located oppositely of cutting edge. With this configuration is possible to use four edges of the tool.

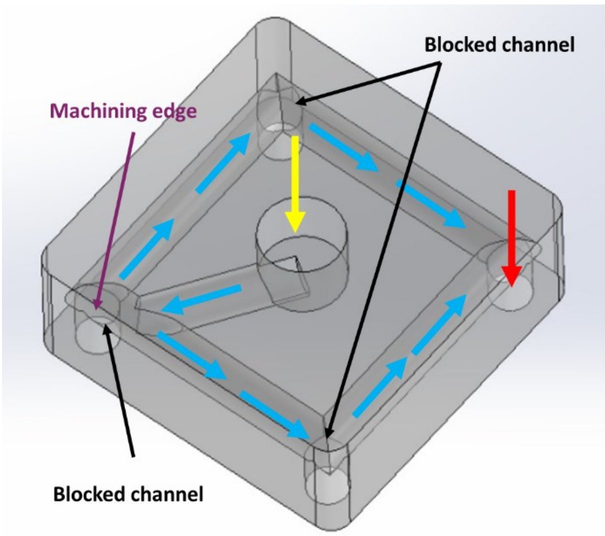

Figure 2. Modified Insert (França, 2021).

The tool holder used is a DSSNL2525X12-P model, this support already had internal cooling channels (Figure 3), but it was modified with an adaptation in its internal fluid channels. To carry out the project, the support underwent some changes in its structure, originally it had a fluid channel directed to the exit surface of the tool and another channel directed to the clearance surface, where the blue parts represent the internal channels in the tool holder. From the modifications made, the lower left channel was capped, and the clamp was altered so that the fluid could enter through the upper part of the tool.

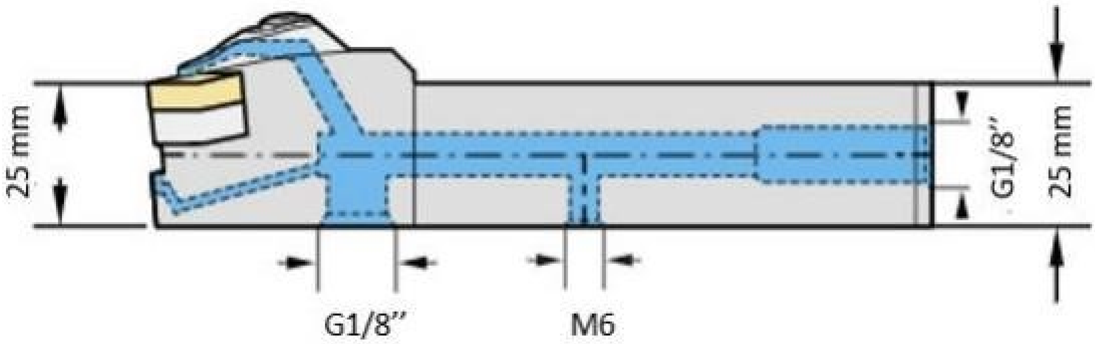

Figure 3. Original internal tool holder channels (Walter Tools, 2021).

3. METHODOLOGY

The bars used were FUCO-300® gray cast iron in accordance with the ABNT NBR 6589 standard, with a diameter of 75 mm and length of 305 mm. To study the influence that modified tools with coolant channels generate on the roughness of external cylindrical turning of gray cast iron, it was decided to use as cutting parameters three cutting speed levels, keeping the feed and depth of cut constant at 0.095 mm/rev and 1.25 mm. The speed levels were chosen so that it is possible to study the finishing effect of using the tools over a long range of values. For each test a time of 40 seconds of machining were stipulated. As ambient conditions, two levels were used, corresponding to the cooling process performed on the tool, being: dry (common insert), cooled with water at a temperature close to the solidification temperature (around 2 ºC). The water flow used in the tools was 500 ml/min. For each machining condition, a replica was made. Table 1 shows the cutting parameters used to carry out the tests.

Table 1. Cutting Parameters.

Cutting Parameters	
Cutting Speed (m/min)	84 - 132 - 212
Feed (mm/rev)	0.095
Depth of cut (mm)	1.25
Enviroment (-)	Modified Tool - Dry

For the roughness measurements, a Mitutoyo SJ-201 P roughness meter was used. The ISO 4288 standard was adopted with the 2.5 mm for sampling length and (2 mm < Ra <10 mm) for cut-off (λ). In this work, the roughness parameters Ra, Rz and Rq were evaluated. For each machining condition, 5 measurements were performed.

4. RESULTS & DISCUSSION

4.1 Roughness (Ra)

The graph in Figure 4 illustrates the roughness measurement results of the Ra parameter of the tests.

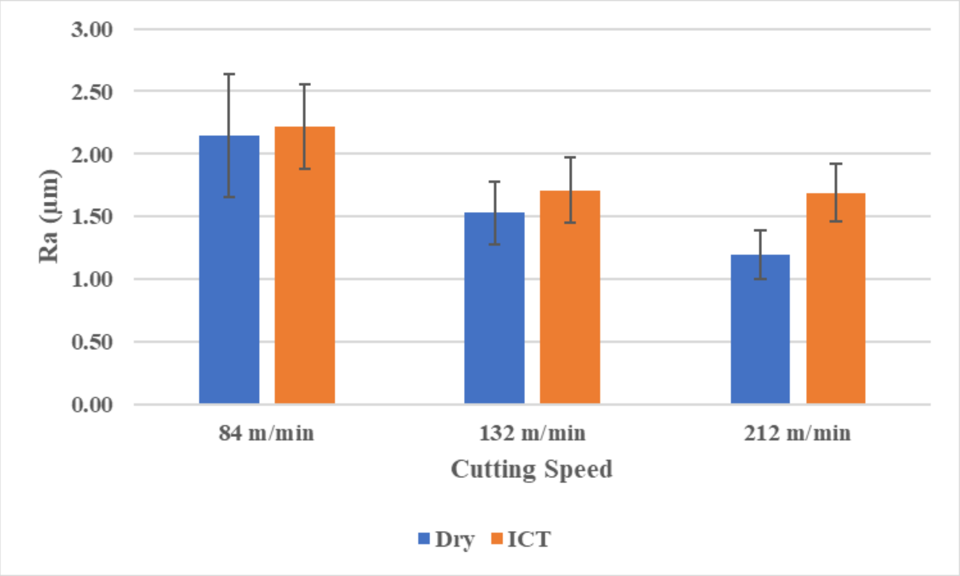

Figure 4. Roughness (Ra) obtained in machining tests.

At dry cutting conditions, as the cutting speed increased, the mean roughness of Ra reduced, what is in agreement with the literature (Lu *et al.*, 2020; Sivaprakasam and Hasan, 2020). One hypothesis for this occurrence is that at low cutting speeds, machining forces are greater, which can generate greater vibrations in the system and consequently generate higher roughness values. At high cutting speeds, the temperature rise causes a reduction in the shear strength of the workpiece material, promoting a reduction in machining forces. However, at ICT conditions, at medium to high cutting speeds, no differences in roughness can be seen. One hypothesis for this is the presence of the cooling at tool edge due to water flux internally, preventing the increase in temperature, in this way, increasing machining forces and generating greater vibrations. This fact related to temperature reduction with this technology was studied by (França, 2021) in the turning of gray cast iron, where was checked that this system can reduce the cutting temperature up to 21.52 %. (Barbosa, 2021) studied this system in the turning of hardened steel AISI D6, and was showed that this system can causes an increase in cutting forces comparing to dry cutting.

When analyzing the graph, it can be seen that was no difference in roughness between using a common and cooled tool. To check this statistically, an analysis of variance (ANOVA) of the tests and replicates was performed, as indicated in Table 2.

Table 2. ANOVA for Roughness (Ra).

Fator	SS	df	MS	F	p-value
Environment	0.167131	1	0.167131	2.84402	0.130200
Cutting Speed	1.169133	1	1.169133	19.89481	**0.002110**
Environment X Cutting Speed	0.136967	1	0.136967	2.33074	0.165358
Erro	0.470126	8	0.058766		
Total SS	1.915960	11			

The column written in red indicates the "p" values. For $p > 0.05$ it means that the parameter is not statistically significant at 95 % reliability. It is noted that by the analysis of variance there was no significant relevance in the use of the cooling system in relation to finishing.

Figure 5 shows the Pareto graph for the roughness Ra, where it can be observed that the cutting speed has the greatest significance in the roughness values, with the modified tools being the second most influential, although not statistically significant, and in third place the iteration of the cutting speed using the modified tools. For the environment, the non-significancy can be explained by the fact that cast gray iron are a material with good machinability, containing graphite in its microstructure, which ends up acting as a self-lubricant agent during the cutting process. This same behavior was seen by (Bazon, 2020), that compered the influence of ICT with wet machining in the turning of cast gray iron.

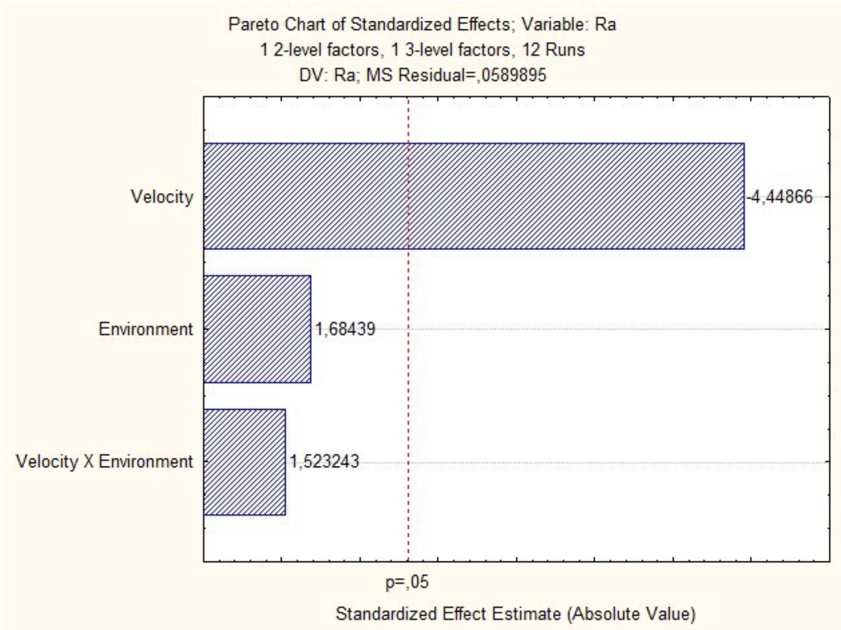

Figure 5. Pareto Chart for Roughness (Ra).

4.2 Roughness (Rz)

The graph in Figure 6 illustrates the roughness measurement results of the Rz parameter of the tests.

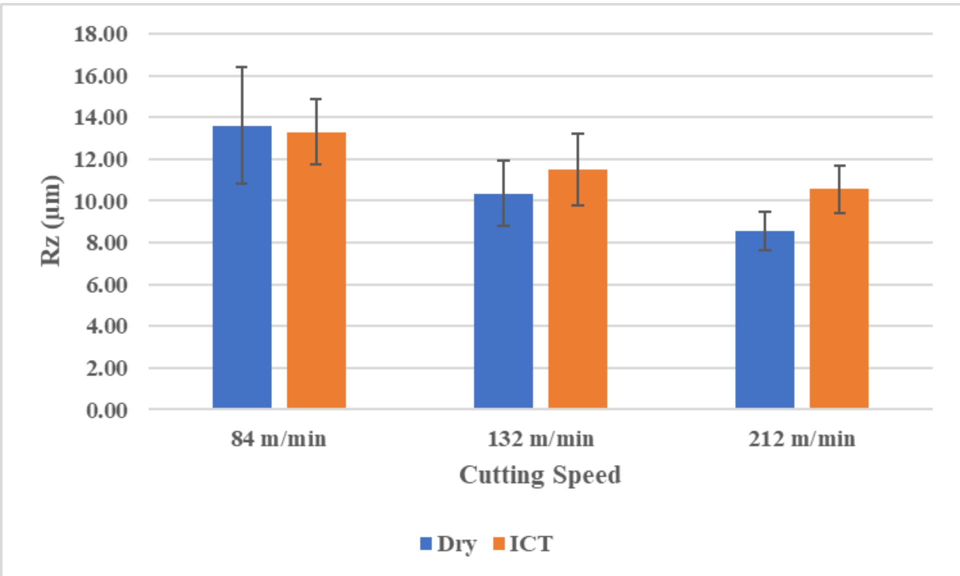

Figure 6. Roughness (Rz) obtained in machining tests.

Note that the behavior of the graphics presented had the same behavior for the Ra parameter. At low cutting speeds, it was not possible to notice a significant difference between the use of cooled tools. However, by increasing the cutting speed, he realized higher roughness values for the cooled tools. In addition, it was also possible to notice a decrease in roughness with an increase in cutting speed comparing the minor value with intermediary and high. When performing the ANOVA analysis of the system (Table 3), it was possible to perceive a significance only in the cutting speed parameter, indicating that the cooling system does not significantly change the Rz roughness.

Table 3. ANOVA for Roughness (Rz).

Fator	**SS**	**df**	**MS**	**F**	**p-value**
Environment	0.254250	1	0.254250	3.49533	0.098471
Cutting Speed	1.532936	1	1.532936	21.07419	**0.001777**
Environment X Cutting Speed	0.192320	1	0.192320	2.64394	0.142598
Erro	0.581920	8	0.072740		
Total SS	2.521407	11			

Figure 7 shows the Pareto graph for the Rz roughness, where, as well as the Ra, it can be observed that the cutting speed has the greatest significance in the roughness values, while the non-significant condition of the modified tools and in third place the cutting speed iteration using the modified tools.

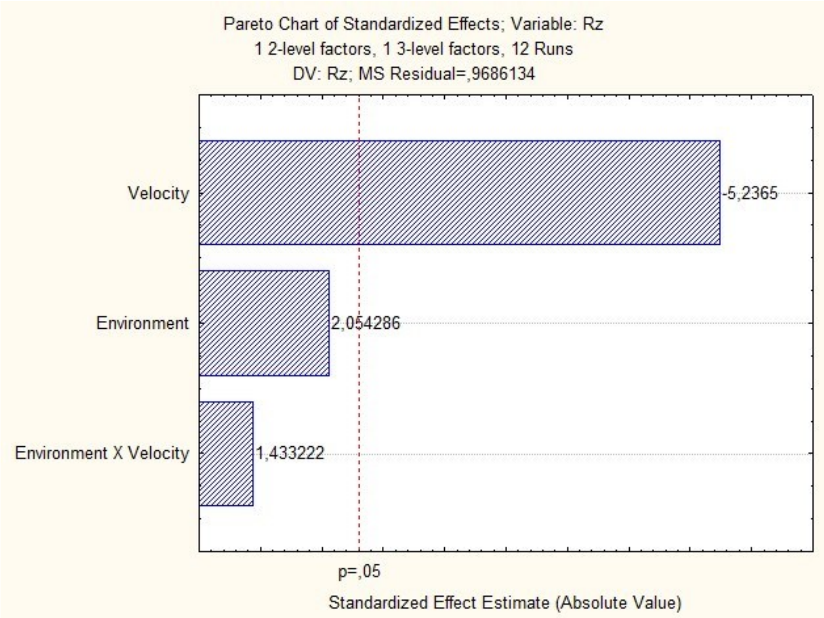

Figure 7. Pareto Chart for Roughness (Rz).

4.3 Roughness (Rq)

The graph in Figure 8 illustrates the roughness measurement results of the Rq parameter of the tests.

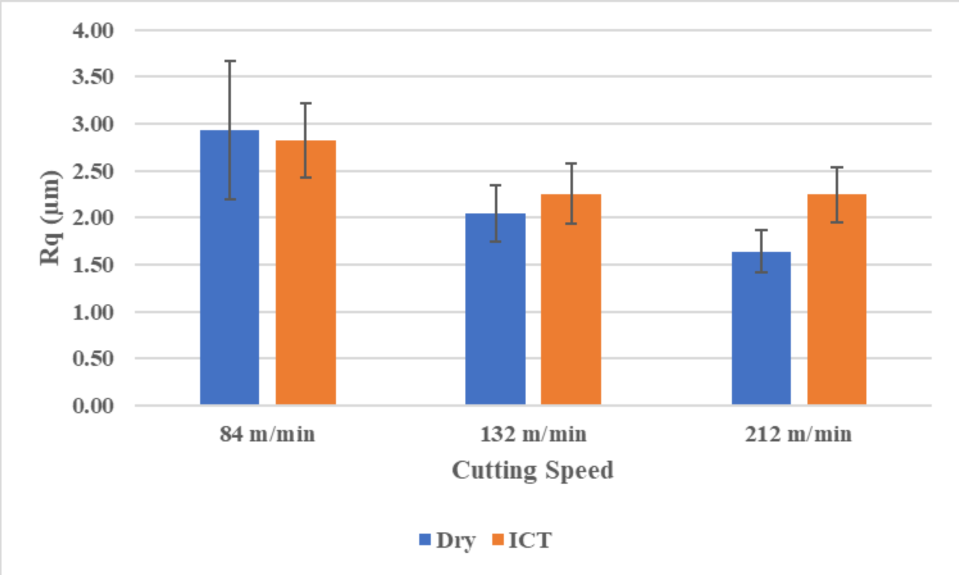

Figure 8. Roughness (Rq) obtained in machining tests.

As the cutting speed increased, comparing the lowest parameter with the medium and high, the mean roughness of Rq also reduced. The explanation for this occurrence is the same for Ra and Rz, which is due to the reduction in cutting forces due to the loss of material strength due to high temperatures. Table 4 shows the ANOVA analysis performed for this parameter.

Table 4. ANOVA for Roughness (Rq).

Fator	SS	df	MS	F	p-value
Environment	4.08375	1	4.08375	4.23557	0.073583
Cutting Speed	26.59220	1	26.59220	27.58079	**0.000772**
Environment X Cutting Speed	1.99337	1	1.99337	2.06747	0.188413
Erro	7.71325	8	0.96416		
Total SS	39.86937	11			

Note that the only significant parameter was also the cutting speed, indicating that the cooling system does not significantly alter the roughness Rq.

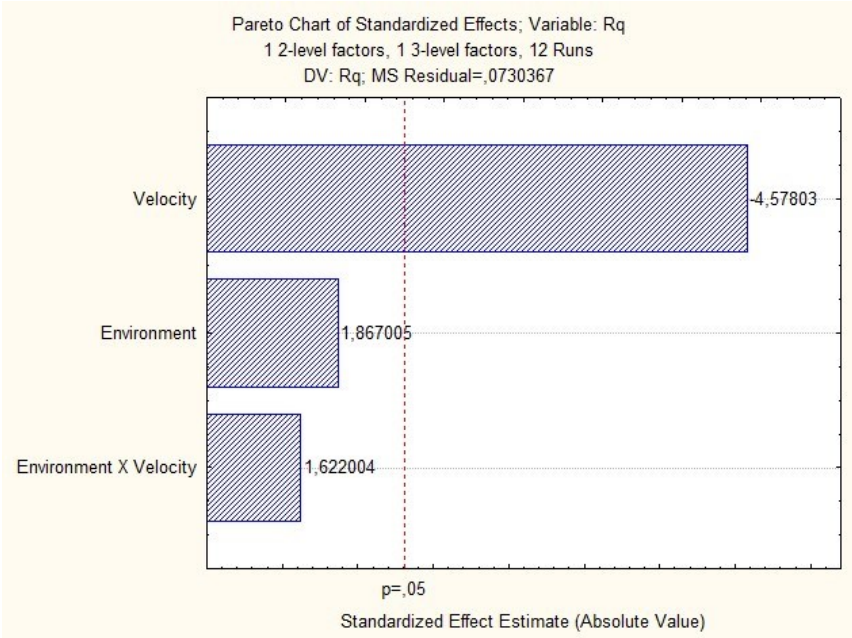

Figure 9. Pareto Chart for Roughness (Rq).

Figure 9 shows the Pareto graph for Rq roughness, where speed was the most significant parameter during machining, while the Environment parameters and its iteration with the cutting speed were not relevant.

5. CONCLUSIONS

After performing the tests, the following conclusions were obtained.

- Through the analysis of variance and the Pareto diagram, it was possible to conclude that the cutting speed was the most significant parameter in the roughness values Ra, Rz and Rq.
- By increasing the cutting speed, lower roughness values were obtained.
- For all the tests, the use of cooled tools resulted in an worst in finish for both roughness parameters Ra,Rz and Rq. However, according to analysis of variance and Pareto diagram this increase was not statistically significant.

6. ACKNOWLEDGEMENTS

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